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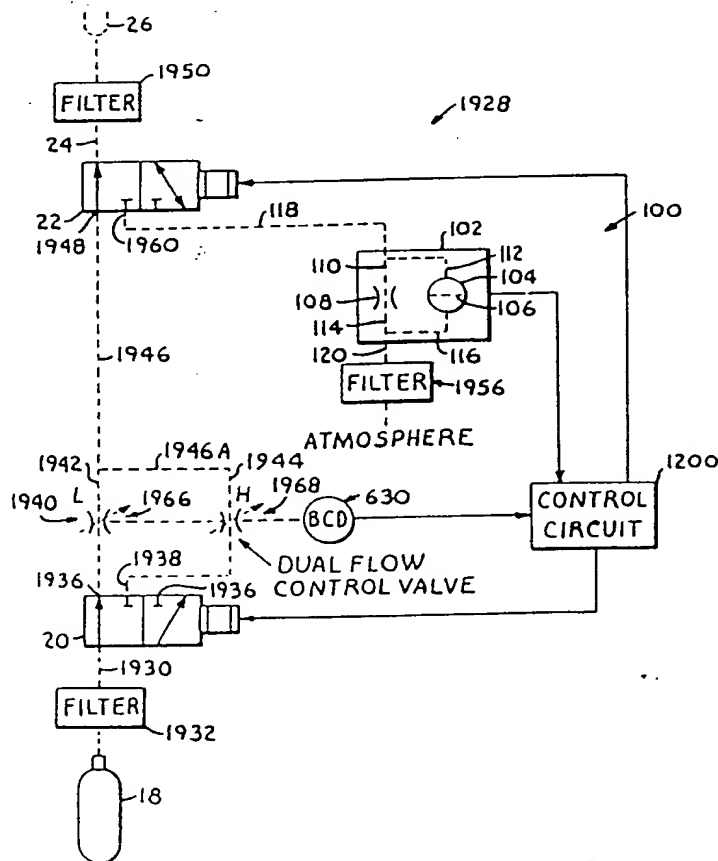
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(54) Title: METHOD/APPARATUS FOR INSPIRATIONAL GAS SAVING**(57) Abstract**

A reliable, pulse-flow supplemental oxygen apparatus (1928) for alleviating respiratory ailments which yields substantial savings in oxygen while giving the patient the physiological equivalent of a prescribed continuous stream of oxygen. The apparatus (1928) preferably includes a demand oxygen valve (22) operated in a pulse mode by means of electronic control circuitry (1200) which, through an appropriate sensor (100), monitors the patient's breathing efforts and gives a variable 'custom tailored' pulse volume of oxygen to the patient during the very initial stages of each inspiration. The apparatus (1928) is also designed to revert to conventional, continuous-flow operation upon a power failure or circuit malfunction, and for this purpose a specialized dual flow control restrictor valve (1940) is provided in the form of the invention designed for hospital use. Actual tests with the apparatus (1928) hereof demonstrate an oxygen saving of over 50 % as compared with continuous flow regimens.



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1 METHOD/APPARATUS FOR INSPIRATIONAL GAS SAVING

Background of the Invention1. Field of the Invention

5 The present invention is concerned with supplemental medicinal gas delivering devices designed to supply to a patient effective amounts of medicinal gases such as oxygen. Devices of this character are commonly used in the treatment
10 of various lung ailments, for example, emphysema. More particularly, the invention is concerned with a greatly improved gas therapy apparatus which is designed to save substantial quantities of medicinal gas, as compared with the conventional and
15 time-honored approach of simply supplying a continuous stream of such gas to the patient. This savings is accomplished by controlling the length as well as the timing of the periods during which oxygen is supplied to the patient in a unique
20 manner in response to the timing of the patient's own breathing efforts. Moreover, the invention comprehends a unique flow control valve designed for use in such gas therapy applications, together with electronic circuitry to provide precise,
25 reliable control under normal and extraordinary conditions encountered in the treatment of patients.

2. Description of the Prior Art

30 Many patient suffering from diseases of the respiratory system are treated through the use of supplemental oxygen or other gas. Very commonly, and particularly in the case of supplemental oxygen, the administration technique has involved
35 nothing more than applying a continuous stream of

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1 oxygen to the patient through a nose cannula or
similar device. Thus, a physician may prescribe a
given flow rate of oxygen for a patient, and a
5 simple control valve is set to deliver the pre-
scribed flow rate.

While this approach does provide the
patient with supplemental oxygen, it is extremely
wasteful from the standpoint of oxygen usage.
That is to say, physiological studies have demon-
10 strated that much of the oxygen delivered to a
patient during a breathing cycle is wasted; it may
simply be directly exhaled or never reach the
lungs. In fact, prior studies have established
that the physiological equivalent of continuous
15 oxygen delivery can be achieved by administering
relatively short, high flow rate pulse volumes of
oxygen at the beginning of the inspiration cycle,
and that if properly done such a therapy is just
as effective as continuous administration of
20 relatively lower flow rates of gas.

Apart from the gas waste inherent in
continuous systems, it is also generally necessary
to humidify a gas which is being continuously
delivered to a patient. This may be accomplished
25 by bubbling the gas through a humidifier prior to
delivery to the cannula. While such humidifiers
are well known, they present a problem inasmuch as
the moist environment of the humidifier can be a
significant vector for the transmission of infec-
30 tion. This problem can be especially acute in the
case of weak or non-ambulatory patients, as will
be readily appreciated.

Patent No. 4,457,303 to Durkan describes
a respirator apparatus designed for intermittent
35 demand oxygen flow and apneic event detection.

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1 The structure described in this patent provides a
selectively settable device which, at an appro-
2 appropriate time during a patient's breathing cycle,
will deliver a predetermined quantity of gas in
5 the form of a fixed time duration pulse. A prime
deficiency of this approach, however, is the fact
that the device cannot automatically adjust the
pulse volume delivered over time to accommodate
different patient breathing rates and conditions.
10 Thus, the Durkan apparatus is preset to deliver a
constant, predetermined pulse volume, and does so
notwithstanding variations in demand on the part
of the patient or other external factors. Thus,
if the patient begins to breathe rapidly, the
15 effective result may be a near-continuous flow of
gas, whereas if the patient breathes more slowly
only relatively small, widely spaced doses are
delivered. In short, the Durkan device provides
no "on-the-go" operational flexibility, but rather
20 supplies a constant dose of oxygen under all
conditions once set.

Summary of the Invention

25 The present invention provides a greatly
improved device for supplying supplemental doses
of medicinal gases in a manner to obtain equal (or
more favorable) physiological results, as compared
with the prior technique of continuous gas admini-
stration. A prime feature of the invention stems
30 from the fact that the volume of gas delivered in
each individual pulse is varied depending upon the
patient's ongoing breathing rate. As such, the
invention provides "custom-tailored" supplemental
gas pulse volumes which are specifically and
35 continuously adjusted to match the breathing rate

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1 of the patient and the physician prescribed dose.
In addition, clinically this invention delivers a
preprogrammed volume of gas per unit of time
5 depending upon the physician-selected prescrip-
tion. This volume may advantageously be constant
or could be programmed to vary in a nonlinear
fashion depending upon medical need.

In more detail, the apparatus of the
invention is adapted for connection between a
10 source of medicinal gas (e.g., pressurized oxygen)
and a patient-coupled gas delivery device such as
a nasal cannula or like expedient. The apparatus
is designed for supplying pulse volumes of the gas
to the patient from time to time during the pa-
15 tient's breathing cycles, and, in the case of
oxygen, at the very beginning of inspiration
during each breathing cycle. In general, the
apparatus includes selectively actuatable valve
means which may be a valve, flow proportioner, or
20 the like adapted for coupling between the gas
source and the delivery device for selectively
establishing and interrupting gas flow communica-
tion therebetween. In addition, electronically
controlled actuating means is provided for selec-
25 tively operating the valve means, and includes
breathing cycle sensing means and electronic means
operably coupled with the sensing means for mea-
suring a parameter characteristic of at least one
of the patient's breathing cycles, and for provid-
30 ing a value correlated with the measured time
interval. Finally, means is connected between the
measuring means and the valve means for actuating
the latter in order to establish the gas flow
communication for a period of time which varies in
35 response to the assigned parameter value.

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1 In preferred forms of the invention, the
sensing means is in the form of an extremely
sensitive pressure or flow sensing device or the
like operatively coupled through the valve and gas
5 delivery device to the patient's breathing pas-
sages. Other types of breathing cycle sensing
means could also be used, e.g., those measuring
breath flow rate, breath flow direction, breath
temperature, breath humidity, breath oxygen con-
10 tent, breath carbon dioxide content or breath
sounds; the goal in each case, of course, is to
sense a parameter characterizing the breathing
cycle. The preferred measuring apparatus includes
structure for measuring a time interval which
15 characterizes at least a part of one of the pa-
tient's breathing cycles (e.g., the duration of
inhalation). This time interval is advantageously
the duration of a plurality of breathing cycles
including both inhalation and exhalation. The
20 connecting means between the time measurement
apparatus and valve means comprises control cir-
cuitry designed to receive input data from the
measuring apparatus, to provide a value correlated
therewith, and to correspondingly generate an
25 output signal in response to such input data which
controls the valve actuation timing. Thus, in
preferred forms, the period of time during which
the valve means is open, and hence gas is being
delivered, varies in relation to the input signal
30 values received.

 In one particular embodiment of the
invention designed for hospital or institutional
use, a demand valve of the type described above is
employed. In addition, however, a secondary dual
35 flow control arrangement in series with the demand
valve is also provided which, in the normal pulse-

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1 mode position of the overall apparatus, delivers a
relatively high flow rate of gas to the downstream
demand valve which in turn is operated in the
desired pulse mode. However, during abnormal or
5 upset conditions, the series flow control device
delivers a continuous flow of gas at a lower
predetermined prescribed flow rate. This dual
flow rate device thus permits the unit to be set
to the physician's prescribed flow rate, and
10 thereby achieve substantially the physiological
equivalent of such prescribed flow rate in both
the pulse mode and the continuous flow mode.

In another embodiment of the invention
principally designed for home use, the dual flow
15 control device is eliminated. In this case,
physiologically equivalent pulse volumes are
assured by virtue of the fact that, during the
relatively long time that the demand valve is
closed during each breathing cycle, excess gas
20 builds up in the equipment between the valve and
gas source (e.g., a dynamic pressure regulator).
As a consequence, when the valve is again opened
to deliver a pulse of gas, the excess pressure is
quickly released to give a desired, high peak rate
25 pulse of gas to the patient.

The pulse volume supply apparatus of the
invention is also equipped with numerous safety
features assuring that, in the event of a malfunc-
tion or abnormal breathing efforts on the part of
30 the patient, the unit is switched to a continuous
mode at the prescribed flow rate. Hence, one such
feature involves provision of means for sensing
the breath rate of the patient. If this breath
rate is above or below preselected limits, the
35 device is shifted to the continuous flow mode for

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1 a substantial period of time greatly in excess of
a usual peak pulse time (e.g., 7.5 seconds). At
the end of this continuous flow time period, the
unit then reverts to the pulse flow mode for at
5 least a minimum period of time, until another
abnormal breathing condition is detected. In like
manner, in the event of a power outage to the unit
or circuit failure, the device is automatically
shifted to the continuous flow mode. To this end,
10 the demand valve employed is preferably a three-
way solenoid valve mechanically biased to the
continuous flow condition thereof. Thus, upon
power outage, the valve simply shifts to the
continuous flow orientation thereof.

15 The gas pulses generated by the appa-
ratus of the invention are designed for delivery
to the patient at the very early stages of inspi-
ration during each breathing cycle. In practice,
pulse flow is initiated within about 15 to 60
20 milliseconds after the patient begins to inspire.
As a consequence of this operational characteris-
tic, an extremely sensitive inhalation sensor is
employed. By virtue of this extreme sensitivity,
the sensor device itself is subject to ambient-
25 induced signal drift, which, if uncorrected over
time, could lead to inaccuracies in pulse volume
delivery. However, the present invention over-
comes this potential problem by provision of
automatic rezeroing circuitry which, at the end of
30 each delivered gas pulse when the inhalation
sensor is pneumatically isolated from the gas
delivery device, electronically puts into memory
an appropriate inhalation sensor rezeroing signal
to be used as a reference during the next breath-
35 ing cycle. In this way, the system is continuous-

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1 ly rezeroed so as to compensate for any ambient-
induced drift in the sensor.

5 Brief Description of the Drawings

Figure 1 is a schematic representation
of the preferred arrangement of pneumatic compo-
nents and electronic circuitry of the inhalation
sensor portion of the overall controller device of
the invention, with significant pneumatic compo-
nents of the "hospital" embodiment of the inven-
tion also being illustrated;

Fig. 2 is an electrical schematic draw-
ing illustrating the preferred clock and monitor
circuit forming a part of the overall controller
device;

Fig. 3 is an electrical schematic draw-
ing illustrating the preferred flow initiation and
rezeroing circuitry of the overall device;

Fig. 4 is an electrical schematic draw-
ing depicting the solenoid control and monitoring
circuit of the overall device;

Fig. 5 is an electric schematic drawing
illustrating the preferred three-breath timer
circuitry forming a part of the complete control-
ler device;

Fig. 6 is an electrical schematic draw-
ing showing the preferred flow pulse circuitry
making up a part of the complete controller de-
vice;

Fig. 7 is an electrical schematic draw-
ing illustrating the circuitry associated with the
blanking function of the complete controller
device;

Fig. 8 is an electrical schematic draw-
ing depicting the preferred reset and power moni-
toring circuitry of the device;

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1 Fig. 9 is an electrical schematic drawing showing the preferred failure indicator circuitry of the device;

5 Fig. 10 is an electrical schematic drawing depicting the audible alarm circuitry making up a portion of the overall controller device;

10 Fig. 11 is an electrical schematic drawing depicting the preferred seek/deliver circuitry;

 Fig. 12 is a block diagram illustrating the primary interconnections between the functional modules of the device;

15 Fig. 13 is a series of four time graphs respectively illustrating the patient respiratory pressure wave form, the pulse flow wave form of delivered gas pulses for both the "home" and the "hospital" embodiments, the time operational characteristics of the demand solenoid valve of the invention, and wave form of the output from the system blanking circuitry;

20 Fig. 14 is an essentially schematic cross-sectional view illustrating the configuration of the preferred dual flow control valve used in the invention;

25 Fig. 15 is a perspective view of the dual flow control valve;

30 Fig. 16 is a cross-sectional view of the valve illustrated in Fig. 15, depicting in detail the construction of the central flow control disc;

 Fig. 17 is a partially sectional view taken along line 17-17 of Fig. 16;

35 Fig. 18 is a partially sectional view taken along line 18-18 of Fig. 16;

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1 Fig. 19 is a block diagram illustrating
the pneumatic components of the preferred "hospital"
embodiment of the invention; and

5 Fig. 20 is a block diagram illustrating
the pneumatic components of the preferred "home"
embodiment of the invention.

Detailed Description of the Preferred Embodiments

I. Pneumatic Circuits and Operation

10 A. The oxygen control apparatus in accordance with the present invention, in broad outline, includes a pneumatic circuit and a corresponding electrical control circuit. In the presently contemplated forms of the invention, there
15 is provided a so-called "hospital" unit (Fig. 19) designed to be used in the institutional setting of a hospital or similar health care facility, and also a "home" unit (Fig. 20) designed to be used
20 by the patient at home. In addition, it is also within the ambit of the invention to provide units designed for other specific purposes such as patient transport, and also for use in conjunction with an oxygen concentrator.

25 The supplemental medicinal gas supply systems of the invention (see, e.g., Fig. 1) normally include a pressurized source of medicinal gas 18, which would typically be oxygen, together with an electrically operated three-way demand solenoid valve generally referred to by the numeral
30 22 which is operatively coupled to the source 18 and is operated through the electrical control circuitry in a manner to be described in detail. Further, a gas output line 24 is operatively secured to the demand solenoid valve 22, and has
35

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1 the usual nasal cannula 26 secured thereto for delivery of medicinal gas to the patient.

5 Attention is next directed to Fig. 19 which illustrates in schematic form the so-called "hospital" unit and particularly the pneumatic circuitry and components associated therewith. Such hospital unit is broadly designated by the numeral 1928, and includes the noted oxygen source 18 and solenoid valve 22. In addition, however, 10 and as shown in Fig. 19, the unit 1928 is provided with a line 1930 from the source 18, with a conventional filter 1932 interposed within the line 1930.

15 As illustrated, the line 1930 is operatively connected to an inlet port of a three-way flow solenoid valve 20. This valve 20 includes a pair of outlet ports 1936, 1938 which are each connected to corresponding inlets provided with a dual flow control valve broadly referred to by the 20 numeral 1940. This valve 1940, illustrated in detail in Figs. 14-18, will be described more fully below. For purposes of the present discussion, however, it is sufficient to recognize that the valve 1940 includes a pair of respective, low 25 and high flow outlets 1942, 1944. These flow outlets are in turn operatively connected through lines 1946 and 1946a to one inlet 1948 of the demand solenoid valve 22. As is typical in devices of this character, a conventional filter 1950 30 is interposed within patient gas output line 24 between valve 22 and cannula 26.

The overall device 1928 further includes pneumatic/electrical sensing apparatus broadly referred to by the numeral 100 which is designed 35 to sense the beginning of the patient's inhala-

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1 tion, such being significant to the proper operation of the overall device. In detail, the sensing apparatus 100 includes a pressure sensor 102, a restrictor 108 and a filter 1956. A pneumatic
5 line 118 is provided between the second inlet port 1960 of valve 22 and pressure sensor 102. Moreover, another pneumatic line 114 is operatively coupled with line 118 ahead of sensor 102, and
10 filter 1956; moreover, it will be seen that the restrictor 108 is interposed within the line 114. Finally, another pneumatic line 116 is operatively coupled to the sensor 102 and line 114 between restrictor 1954 and filter 1956.

15 The pressure sensor 102 includes an internal diaphragm 106, the operation of which is described in full detail below.

20 The dual flow control valve 1940 is operable for permitting selection of a prescribed flow of medicinal gas to the patient by means of an external knob and selector dial. Internally, and again in a generalized sense, the valve 1940 includes a low or prescribed flow restrictor in the form of a plurality of differently sized
25 orifices as will be explained, together with a high, pulse flow restrictor 1968, which again is in the form of a plurality of differently sized apertures. Finally, the valve 1940 includes a binary coded decimal encoder 630 which serves to
30 output binary electrical data corresponding to the gas flow rate selected by the user when employing the valve 1940.

35 The electrical aspects of the overall device 1928 includes control circuitry 1200 which is associated with the above-described pneumatic components by the schematically illustrated full

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1 lines. Thus, the control circuitry is operatively
connected to the flow solenoid valve 20, the
encoder 630, pressure sensor 102, and demand
5 solenoid valve 22. Here again, the specific
interconnections and details regarding control
circuitry 1200 are set forth hereinafter.

The device 1928 is designed to normally
operate in a manner to deliver to the patient
relatively high flow rate, short time pulses of
10 oxygen at precisely timed intervals during the
patient's breathing cycle, which are designed to
be essentially the physiological equivalent of
delivery of relatively low flow rates of gas to
the patient on a continuous basis. However, the
15 safety and control features of the device are
associated with the valves 20, 22 in such manner
that the unit is shifted to the conventional con-
tinuous flow mode of operation upon the occurrence
of power failure, abnormally high or low breath
20 rates or various circuit failures within the
control circuitry 1200.

In any event, during such normal opera-
tion the user first rotates a dial (not shown)
associated with the dual control valve 1940, to a
25 position corresponding to a continuous flow rate
of gas prescribed by the physician. That is to
say, physicians almost universally prescribe a
certain rate of oxygen or other gas to the pa-
tient, e.g., 5 liters per minute. The knob asso-
30 ciated with the valve 1940 would then be turned to
a position corresponding to such flow rate, al-
though it will be understood that the overall
device does not normally supply such flow rate on
a continuous basis; rather, during normal opera-
35 tion, the substantially physiological equivalent

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1 of the prescribed flow rate is supplied using the
precisely timed, high flow rate pulses of gas to
the patient.

5 When the valve 1940 is manipulated as
described, the high flow rate restrictor 1968 is
adjusted to position an appropriately sized aper-
ture for communication with outlet port 1944 of
the valve 1940. At the same time, the binary
10 coded decimal encoder 630, being operatively
connected to the handle, generates a digital
electrical output which is directed to control
circuitry 1200 in order to "set" this circuitry in
operation in accordance with the prescribed flow
rate.

15 Again referring to the normal operation
of the device 1928, the control circuitry 1200
serves to normally continuously energize the flow
solenoid valve 20 in order to continuously commu-
20 nicate gas line 1930 with outlet port 1938 of the
valve 20. On the other hand, the control circuit-
ry 1200 selectively energizes and de-energizes the
demand solenoid valve 22 so as to deliver the
noted "pulses" of oxygen or other medicinal gas to
the patient. Thus, and considering the period of
25 initial inspiration wherein oxygen is to be deli-
vered to the patient, the demand valve 22 is in
the position illustrated in Fig. 19, i.e., it is
de-energized. In this condition, it will be
appreciated that gas from the source 18 travels
30 via line 1930 through valve 20 to outlet port
1938. Thereupon, gas passes through the selected
orifice forming a part of the high or pulse re-
strictor 1968, and thence through high flow outlet
1944. The gas then passes through the lines 1946a
35 and 1946 to the inlet port 1948 of de-energized

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1 valve 22 for ultimate delivery via line 24 to
cannula 26.

5 On the other hand, during those stages
of the patient's breathing cycle where no oxygen
is being delivered, the demand solenoid valve 22
is energized, and is moved leftwardly from the
position depicted in Fig. 19. As can be seen,
this moves the port 1960 into communication with
gas flow line 24 and port 1948 out of communica-
10 tion with line 24, thereby stopping flow of oxygen
to the patient.

Furthermore, in this energized position
of the solenoid valve 22, the line 118 is in
communication with gas line 24 leading to the
15 cannula 26. The patient inhales a very small
amount of ambient air through filter 1956 and
restrictor 108. This correspondingly creates a
pressure differential across the restrictor 108
which is communicated to both sides of the dia-
20 phragm 106 forming a part of pressure sensor 102,
via the pneumatic lines 118, 116. Of course,
during exhalation when the solenoid 22 is ener-
gized, exhaled air passes likewise through the
line 24, valve 22, and lines 118, 114. Therefore,
25 both during inspiration (except when the gas pulse
is being delivered) and exhalation, corresponding
pressure differentials are created across the
restrictor 108, such being sensed by the diaphragm
106 of sensor 102. The diaphragm 106 is equipped
30 with appropriate electrical, variable resistors on
the face thereof in such a manner that upon dia-
phragm distortion an electrical signal analog of
the sensed pressure differential is created. Such
differential pressure analogs, created during the
35 patient's breathing cycle when the valve 22 is

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1 energized, are communicated by appropriate electrical lines to the control circuitry 1200.

5 As noted above, under certain unusual or upset conditions, the device 1928 operates in the conventional continuous flow mode. In order to accomplish this operation, both of the solenoid valves 20, 22 are continuously de-energized, to the condition depicted in Fig. 19. As a consequence, it will be seen that gas from source 18
10 passes through line 1930 and thence through outlet port 1936 of valve 20. Such gas thereupon flows through the selected orifice of the low flow restrictor 1966 and thence through outlet 1942 to line 1946. Such line is coupled through the
15 solenoid valve port 1948 to line 24 and ultimately to cannula 26.

As will be explained further below, the operating mechanism forming a part of the dual flow control valve 1940 serves to set both the low
20 and high flow restrictors, as well as BCD encoder 630. Thus, when a physician prescribes a given continuous flow rate of oxygen, and the valve 1940 is correspondingly set, the appropriate high flow restrictor orifice is positioned for flow communication purposes, and simultaneously the appropriate low or continuous flow aperture is also set to
25 accommodate the power off or upset conditions giving rise to continuous flow operation. In addition, of course, manipulation of the control valve also sets the encoder 630, to communicate the dial setting to control circuitry 1200.
30

Attention is next directed to Fig. 20 which illustrates in schematic for the pneumatic/electrical components of the so-called "home"
35 controller 2000. The structural differences

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1 between the unit 2000 and the unit 1928 described
above are principally based upon the fact that in
hospital or institutional settings, the pressure
5 of oxygen or other medicinal gas supplied to the
system is essentially uniform (e.g., 50 psig). On
the other hand, in the home context the gas pressures
can vary widely, and therefore precautions
must be taken to properly accommodate such pressure
variations.

10 In any event, the device 2000 is in many
respects similar to that of Fig. 19, and where
appropriate like reference numerals have been
employed. The device 2000 therefore is used in
conjunction with a supply 18 coupled with a flow
15 line 2002. A variable flow control device 2004 is
interposed within line 2002, along with a filter
2006 and a pressure regulator 2008. The flow
control device 2004 is a manually operated unit
designed to restrict the flow of gas from the
20 supply 18 at a setting corresponding to the prescribed
continuous flow of gas. On the other
hand, the regulator 2008 is designed to supply a
continuous, constant pressure output of gas at a
given level, as long as the input pressure to the
25 regulator is at least this given level. Thus, the
pressure regulator may be set to deliver gas at a
pressure of 20 psig, and will do so as long as the
input to the regulator is of at least this magnitude.

30 The output from regulator 2008 is fed
via a line 2010 to the three-way demand solenoid
valve 22. This unit is identical with that described
with reference to Fig. 19, and accordingly
includes a pair of inlet ports 1948, 1960. The
35 outlet from the valve 22 travels through line 24

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1 to cannula 26, all as illustrated in Fig. 20.

In like manner, the device 2000 includes a pressure sensor 102 associated with a flow restrictor 108 and gas flow lines 118, 114 and
5 116, as well as filter 1956.

The unit 2000 further is provided with binary coded decimal encoder 630 which is identical with the encoder 630 described with reference
10 to Fig. 19. However, in this instance, the encoder 630 is individually set, i.e., it is not simultaneously set along with a flow control valve.

The use of the home unit illustrated in Fig. 20 proceeds as follows. First, the continuous flow rate prescription received from the physician is set on the flow control device 2004
15 and on the encoder 630. Setting of the last mentioned component in turn communicates the corresponding digital information to control circuitry 1200. Normal operation of the device 2000 after initial setting thereof proceeds as follows. First, and considering when pulses of oxygen or other gas are to be delivered to the
20 patient, the control circuitry 1200 de-energizes solenoid valve 22, so that the latter assumes the position depicted in Fig. 20. In this orientation, it will be seen that oxygen passes from source 20 through the device 2004, filter 2006, regulator 2008 and line 2010 to inlet port 1948.
25 Such gas thereupon passes through valve 22 through line 24 to cannula 26. The time during which the valve 22 is de-energized is of course controlled by means of the circuitry 1200 in a manner to be
30 explained.
35

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1 In any event, during the majority of the
patient's breathing cycle when no gas is being
delivered, the solenoid 22 is energized thereby
communicating inlet port 1960 of the valve with
5 line 24. In this orientation, it will be seen
that cannula 26 is in communication with pressure
sensor 102 and the related apparatus previously
described, so as to sense and monitor the pa-
tient's breathing cycle, in the same manner as
10 described with reference to the Fig. 19 apparatus.

Inasmuch as the device 2000 includes the
upstream pressure regulation system ahead of valve
22, the wave form of gas flow actually delivered
to the patient varies somewhat as compared with
15 the wave form generated using the device of Fig.
19. That is to say, in the Fig. 19 device, be-
cause of the essentially constant gas pressures
encountered, the wave form of the delivered pulse
is essentially rectangular. On the other hand, in
20 the Fig. 20 device, during the time when valve 22
is energized, gas pressure will build up within
regulator 2008 and line 2010. This follows from
the fact that gas is continuously communicated
from the source 20 to the regulator, even though
25 the valve 22 is energized. As a consequence, when
the valve 22 is de-energized to permit pulse flow
of gas, an initial "puff" of such gas may be
delivered. This in turn means that the wave form
of the pulse of oxygen delivered is not rectangu-
30 lar, but includes an initial spike followed by an
exponential decay. Of course, the patient still
receives the substantially physiological equiva-
lent of the prescribed oxygen flow, but the wave
forms of the delivered pulses are somewhat dif-
35 ferent as compared to the hospital unit of Fig.

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1 19. These wave forms are illustrated in Fig. 13,
graph 1305.

5 As in the case of the Fig. 19 embodiment, the Fig. 20 device provides for continuous oxygen flow to the patient in the event of a power outage, or abnormal breathing or circuitry malfunction conditions. In this operational mode, the control circuitry de-energizes the solenoid valve 22, thereby directly opening the flow path
10 between source 18 and cannula 26 for delivery of oxygen at the prescribed, continuous flow rate.

B. Dual Flow Control Valve

15 Attention is next directed to Figs. 14-18 which illustrates the preferred dual flow control valve 1940. The valve broadly includes a pair of essentially circular, centrally-apertured valve bodies 1400, 1402 each provided with three circumferentially-spaced, outwardly-projecting annular connection bosses 1404-1408 and 1410-1414.
20 As illustrated, the bosses 1404-1408 are designed for alignment with the corresponding bosses 1410-1414, in order to provide through-holes for mounting screws so as to clamp the bodies 1400, 1402 together and mount the same. In addition, the
25 lowermost valve body 1402 includes a total of three integral, downwardly-directed mounting feet 1416-1420 respectively located between and radially inwardly of the circumferential bosses 1410-1414.

30 The uppermost valve body 1400 is provided with a central axial bore 1422 which communicates with a radially outwardly-extending irregular recess 1424. The recess 1424 includes a seal-receiving region 1426 at the junction between
35

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1 bore 1422 and the recess 1424. The body 1402
further includes a pair of outwardly-projecting
connection nipples 1428 and 1430 for inflow of gas
to the valve. The nipple 1428 is provided with a
5 central bore 1432 which extends inwardly into the
valve body 1402 a selected distance, whereupon the
bore turns downwardly for communication with an
annular enlarged region 1433. Similarly, the
nipple 1430 is provided with a central bore 1434
10 which extends radially inwardly within body 1402
for a lesser length than the bore 1432 (compare
Figs. 17 and 18), whereupon the bore 1434 turns
downwardly and communicates with an annular region
1436. Finally, the body 1402 is provided with a
15 continuous, circumscribing, seal-receiving recess
1438 adjacent the lower and outer margin thereof.

The corresponding lower body 1402 is in
many respects similar to the body 1400. Thus, the
body 1402 is provided with a pair of gas outlet
20 nipples 1438, 1440 which are directly beneath the
corresponding inlet nipples 1428, 1430. The
nipple 1438 is provided with an inwardly-extending
bore 1442 which extends into body 1402 the same
distance as corresponding nipple bore 1432, where-
25 upon the bore 1440 turns upwardly to communicate
with enlarged annular zone 1444. Similarly, the
bore 1440 is provided with a somewhat shorter,
inwardly-extending bore 1446 which extends into
body 1402 the same distance as corresponding bore
30 1434, and turns upwardly to terminate at an en-
larged annular region 1448. The body 1402 further
includes a central bore 1450 which communicates
with a recess 1452. The latter is provided with
annular seal-receiving zones 1454 and 1456 adja-
35 cent bore 1450 and proximal to the outer margin of
the body 1404, respectively.

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1 The lower valve body 1402 is also pro-
vided with a deadend bore 1458 in the region
thereof remote from nipple 1438 and oriented
radially inwardly from the outer surface of the
5 body 1402 a distance equal to the radially inward
spacing of the annular regions 1436, 1448, for
purposes which will be made clear. The bore 1458
houses a coil spring 1460, the latter yieldably
supporting a detent ball 1462.

10 The valve bodies 1400, 1402 are designed
for mating interconnection thereof to cooperative-
ly present a through-bore comprising the aligned
central bores 1422, 1450, together with a radially
outwardly-extending recess presented by the recess-
15 ses 1424, 1452 of the respective valve bodies. In
addition, it will be observed that the bores 1432
and 1442 are oriented in a directly opposed rela-
tionship for communication, whereas the shorter
bores 1434, 1446 are similarly positioned for
20 communication therebetween. Finally, it will be
seen that appropriate O-ring seals 1464, 1466,
1468, 1470 and 1472 are provided for creating a
gas-tight valve construction. These seals 1464-
1472 are oriented as illustrated in Fig. 17,
25 within the previously described recesses and
annular regions.

 The overall valve 1940 further includes
a rotatable selector 1474 which includes an elon-
gated upright central shaft 1476 which extends
30 through the bores 1422, 1450 as illustrated. A
selector knob (not shown) is adapted for connec-
tion to the projecting portion of shaft 1476 which
extends above valve body 1400. This knob coop-
erates with a flow rate selector dial, also not
35 shown, which is provided with the valve assembly.

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1 The selector 1474 further comprises a
radially outwardly-extending, disc-like extension
1478 which is integral with the shaft 1476 and
located within the central recess presented by the
5 cooperating valve bodies. The extension 1478 is
provided with two sets of circularly arranged
apertures therethrough which are respectively
oriented for communication with the bores 1432,
1442 and 1434, 1446. That is to say, the inner-
10 most set of apertures 1480 are oriented for commu-
nication with the longer bore set 1432, 1442,
whereas the radially outer bore set 1482 are
positioned for communicating the shorter bore set
1434, 1446.

15 Each of the individual through-bores
making up the sets 1480, 1482 extend completely
through the extension 1478 and are of the same
diameter. It will be noted, however, that the
bores making up the radially outer set 1482 are
20 provided with a circular bevel at the lower ends
thereof adjacent valve body 1402; the importance
of this feature will be explained below. In order
to provide settable, different flow rates of gas
through the valve structure, the extension 1478
25 carries a rigid metallic central apertured disc
1484. This disc 1484 is correspondingly provided
with two sets of orifices 1486, 1488 therethrough.
The orifices making up set 1486 are aligned with
the apertures making up the set 1480 provided in
30 extension 1478, whereas the orifices making up the
outer set 1488 are respectively in alignment with
the apertures making up the set 1482. It will
further be observed that each of the orifices is
of a different diameter, so that the effective
35 cross-sectional area presented for gas flow at
each of the orifice-aperture sets is different.

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1 In order to provide an indexing function
for the valve arrangement, the detent ball 1462 is
designed to successively seat within the extension
apertures making up the radially outer set 1482.
5 As can be appreciated, this provides a sensory
"click" or feel as the selector 74 is rotated, and
further insures that the selector is properly
positioned for each of the possible gas flow
rates.

10 In order to provide an "off" function,
each of the aperture sets 1480, 1482 is provided
with a deadend bore which does not extend com-
pletely through the extension 1478. These bores
are located at the circumferentially offset points
15 1490, 1492 (see Fig. 16) so that when the selector
1474 is rotated 180° from the Fig. 16 position,
the deadended "off" bores serve to interrupt fluid
communication between the nipple bore sets 1432,
1442 and 1434, 1446.

20 As schematically illustrated in Fig. 14,
and further explained hereinabove with reference
to Fig. 19, the shaft 1476 of the selector 1474 is
operatively connected to the binary coded decimal
encoder 630; hence, when a prescribed flow rate is
25 selected using selector 1478, the BCD 630 is
simultaneously operated.

 The operation of the valve 1940 will now
be apparent from the foregoing description.
Specifically, when the user is advised by a physi-
cian of a prescription flow rate of medicinal gas,
30 this flow rate (which would conventionally be
prescribed in liters per minute) is selected using
the knob end dial (not shown). This serves to
rotate the extension 1478 until the appropriate
35 aperture/orifice set for the selected flow rate

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1 comes into communication with the nipple orifices
1432, 1442 and 1434, 1446. For example, if a
prescribed flow rate of 5 liters per minute is
5 selected, the appropriate aperture/orifice set
communicating the prescribed or continuous flow
nipples 1428, 1438 would permit a continuous flow
rate of 5 liters per minute. On the other hand,
the corresponding aperture/orifice set communi-
10 cating the peak or pulse flow nipples 1430, 1440
would permit a somewhat higher flow rate than that
specifically described, so that the device can
deliver the desirable physiological equivalent of
the prescribed continuous flow rate in a pulse
mode.

15 With particular reference to the Fig. 19
schematic representation, it will also be clear
that the outlet port 1936 of solenoid valve 20 is
operatively coupled with the continuous flow inlet
nipple 1428 of the valve 1940, whereas the outlet
20 port 1938 of the solenoid valve 1934 is coupled
with the peak or pulse flow inlet nipple 1430.
Correspondingly, the continuous flow output nipple
1438 corresponds to the previously described
outlet 1942, with the pulse flow outlet nipple
25 1440 corresponding to the outlet 1944. The lines
interconnecting the restrictors 1966 and 1968, and
the encoder 630, likewise correspond with the
previously set selector shaft 1476 and its asso-
ciated structure.

30 II. Electrical Circuits and Operation

A. Overview

Broadly speaking, the main purpose of
the preferred electrical circuitry described in
35 detail in Part II.B. below is to de-energize

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1 demand solenoid 22 near the beginning of the
patient's inhalation to allow oxygen to flow, and
then to re-energize demand solenoid 22 a short
5 time later to thereby provide a precise pulse of
oxygen substantially physiologically equivalent to
a prescribed continuous flow. In order to accom-
plish this purpose reliably, safely, and with
precision, the circuitry and associated pneumatic
10 apparatus does the following: senses valid inha-
lation; calculates the duration of the oxygen
pulse based on both the duration of the three
previous breaths and the prescribed flow rate with
an assumed inhalation-exhalation ratio; de-ener-
15 gizes demand solenoid 22 for a period correlated
with such calculated time and then re-energizes
it; prevents spurious re-triggering of the system
during the balance of the inhalation cycle; and
compensates for drift in the sensitivity of the
inhalation sensor.

20 Additionally, the electrical circuitry
allows for component warm-up after power is ini-
tially turned on, adjusts the operation if the
patient breath rate is outside a predetermined
normal range, adjusts the operation if the patient
25 ceases inhaling through the cannula, and provides
for continuous oxygen flow in the event of power
failure or system failure.

The basic system cycle starting time
reference for the electrical circuitry is derived
30 from the patient breath cycle and is more parti-
cularly, that point in patient inhalation when the
patient's nasal vacuum reaches or exceeds .04 cm.
water. The four graphs of Fig. 13 illustrate the
breath cycle and other events during normal system
35 operation. The four graphs all have a common time

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1 ordinate. Graph 1301 includes plot 1302 of pa-
tient nasal pressure in centimeters water during a
typical breathing cycle versus time. Vertical
5 line 1303 crosses plot 1302 when nasal pressure is
-0.04 cm. water which occurs typically between
about 5 to 50 milliseconds after inhalation be-
gins. Vertical line 1304 crosses the time ordi-
nate 10 milliseconds after vertical line 1303;
10 hence the starting time is 10 milliseconds plus
the time for patient nasal vacuum to reach .04 cm.
water.

Graph 1305 represents the flow wave form
in liters per minute of oxygen flow versus time.
Plot 1306 represents a typical oxygen pulse for a
15 hospital unit with the patient breathing at 20
breaths per minute with a prescribed continuous
rate of two liters per minute. Plot 1307 (dashed
line) represents a typical oxygen pulse for the
home unit also at 20 breaths per minute and pre-
20 scribed continuous rate of two liters per minute.
Vertical line 1308 indicates the beginning of
oxygen pulses 1306 and 1307 and coincides with
line 1304.

In the preferred embodiment of the
25 present invention an inhalation to exhalation
[I/E] ratio of 1:1.5 is incorporated within a read
only memory of the device later described. That
is, inhalation time is taken to be 40% of the time
of a total breath cycle. With this ratio in mind
30 then, the preferred embodiment, when operated in
the pulse mode, delivers a constant "minute vol-
ume" of gas to the patient irrespective of breath
rate (within normal limits). That is to say, for
example, if the prescribed continuous flow rate is
35 1 liter per minute (1000 milliliters per minute)

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1 the volumetric sum of all the pulses averaged per
minute equals 400 milliliters (40% of 1000 milli-
liters) at all normal breath rates. Of course,
5 other I/E ratios such as 1:2 could also be em-
ployed. Furthermore, it is to be understood that
the present invention contemplates that the I/E
ratio is a parameter which may be independently
measured by direct measurements of both inhalation
10 and exhalation times, to thus produce another
independent variable along with breath rate and
prescribed flow rate. This may be desirable in
some circumstances; however, use of a constant I/E
ratio factor is preferred for a variety of reasons
including marketing economics.

15 Graph 1309 is a plot 1310 of the voltage
applied to the coil of the demand solenoid 22.
When the coil is de-energized, demand solenoid 22
allows oxygen to flow to the patient. When the
coil is energized, demand solenoid valve 22 pre-
20 vents oxygen flow. Vertical line 1311 indicates
the time point in the breath cycle at which the
demand solenoid is de-energized which also coin-
cides with lines 1308 and 1304. Dotted vertical
line 1313 represents the end of the calculated
25 time of the pulse width. The demand solenoid
remains de-energized, however, for an additional
11 milliseconds to allow for rezeroing which is
explained in more detail in the discussion below.
This extra 11 milliseconds during which the demand
30 solenoid is de-energized causes the oxygen pulse
width to be 11 milliseconds longer than it would
be otherwise; however, this is taken into account
in the data used by the circuitry to calculate
35 pulse duration.

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1 In graph 1314, plot 1315 represents the
time, called blanking time, during which the
electrical circuitry does not reinitiate an oxygen
5 flow pulse in response to patient inhalation. If
system blanking did not occur, additional oxygen
flow pulses might occur after the first pulse
because the patient is still inhaling at the end
of the oxygen flow pulse. Thus, the beginning of
10 the blanking time coincides with lines 1304, 1308,
and 1311; blanking time extends well into the
exhale portion of the breathing cycle as shown on
graph 1314.

 Fig. 12 illustrates in block diagram
15 form the primary modules and interconnections of
control circuit 1200 and thereby the primary
relationships therebetween. Circuit 1200 includes
Inhalation Sensor 100, Clock and Monitor 200, Flow
Initiation and Rezero 300, Solenoid Control and
20 Monitor 400, Three-Breath Timer 500, Flow Pulse
600, Blanking 700, Reset 800, Failure Indicator
900, Audible Alarm 1000, and Seek/Deliver 1100.
Circuit 1200 also includes the primary electrical
connection lines which are enumerated and de-
scribed in the discussion below.

25 By way of overview and to provide a
broad outline of primary functions, the control
circuit 1200 will be first considered at the
modular level with reference to Fig. 12. Then,
individual modules and the components thereof will
30 be described in greater detail under II.B. below.

 Inhalation Sensor 100 provides a contin-
uous direct current output voltage 36 correspond-
ing to the patient's breathing cycle (except when
35 solenoid 22 is de-energized). When demand sole-
noid 22 is de-energized, sensor 100 is pneumati-

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1 cally isolated from the patient cannula and the
output voltage is a nominal, mid-range, no-flow
reference voltage - that is, a value representing
no inhalation and no exhalation.

5 Flow Initiation and Rezero [FIR] 300
receives the breathing cycle signal from sensor
100 via line 1202 as input to a comparator; the
comparator also receives an analog reference
10 voltage produced by FIR 300 from a value stored in
memory. If the breathing cycle voltage decreases
to below the reference voltage, then the output
from the comparator goes "off", that is, drops to
0 volts from 5 volts D.C. (the balance of the
15 circuits described in this section are also digi-
tal circuits whose outputs are "on" at +5 volts
D.C. and "off" at 0 volts D.C.). If the breathing
cycle signal voltage is greater than the reference
voltage, then the comparator output is on. The
20 purpose of the reference voltage comparison is to
compensate for electronic drift of the output from
sensor 100. Sensor 100 is so sensitive that
ambient temperature and other factors may cause
sensor 100 output voltage to drift up or down from
nominal. The reference voltage is equal to the
25 sensor 100 output voltage which existed during the
previous breath cycle when demand solenoid 22 was
de-energized and sensor 100 was thus pneumatically
isolated from the patient cannula. Flow Initia-
tion and Rezero 300 also biases the sensor 100
30 reference voltage so that the comparator goes off
when patient nasal vacuum equals or exceeds .04
cm. water. This is done to prevent spurious
indication of inhalation during the normal breath
35 pause following exhalation.

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1 Flow Initiation and Rezero 300 also
incorporates a time delay so that FIR 300 produces
an on output via line 1204 only if the comparator
is off for 10 milliseconds. The end of this 10
5 millisecond delay corresponds to vertical lines
1304, 1308, and 1311 on the graphs in Fig. 13.
This time delay provides additional validation
that genuine patient inhalation has occurred. The
FIR 300 on output is transmitted via line 1204 to
10 Reset 800, Solenoid Control and Monitor 400, and
Blanking 700.

 Clock and Monitor 200 uses a standard
Colpitts oscillator with a ceramic element to
produce a 4 megahertz square wave signal. Clock
15 and Monitor 200 then scales the 4 MHZ. signal into
a series of various 5 V.D.C. square wave signals
ranging in frequency from .1 HZ. to 100 KHZ. which
signals are conveyed over a number of connections
represented by lines 1206 and 1207 to the various
20 circuit modules. Some of these output clock
pulses are inverted depending on needs of the
individual circuit which uses the pulses.

 Clock and Monitor 200 also includes a
circuit for detecting a malfunction of the oscil-
25 lator; these malfunctions include steady on,
steady off, and frequency too low or too high. If
the monitor detects an oscillator abnormality, it
produces an output transmitted via line 1208 to
Reset 800. Clock and Monitor 200 also receives an
30 input from Reset 800 via line 1210 which resets
and resynchronizes various frequency scaling
circuits when Reset 800 receives a flow initiation
signal via line 1204.

35 Reset 800, upon reception of a flow
initiation signal via line 1204, resets Clock and

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1 Monitor 200 as mentioned above and also resets via
line 1212 Seek/Deliver 1100, Audible Alarm 1000,
and Failure Indicator 900, which resetting indi-
cates to these circuits that a valid inhalation
5 has occurred.

Solenoid Control and Monitor [SCM] 400,
upon receiving a flow initiation signal via line
1204, de-energizes demand solenoid 22 via line
1214 which allows oxygen to flow to the patient
10 and which pneumatically isolates sensor 100. In
normal operation, SCM 400 keeps flow solenoid 20
energized via line 1216. Simultaneously with
de-energizing demand solenoid 22, SCM 400 turns
off its normally on output signal via line 1218 to
15 low Pulse 600 and Three-Breath Timer 500.

SCM 400 also monitors both solenoid
valves 22 and 24 for electrical malfunction via
lines not shown. In the event an abnormality is
detected, SCM 400 de-energizes both solenoids 22
20 and 24 which puts the pneumatic system in a con-
tinuous flow mode. SCM 400 also provides an on
signal represented by line 1220 to Audible Alarm
1000 and Failure Indicator 900 when such an abnor-
mality occurs.

25 Blanking 700 receives the flow initia-
tion signal via line 1204 at which time blanking
700 turns off its normally one signal via line
1222 to Three-Breath Timer 500. Blanking 700 also
receives count data via databus 1224 from Three-
30 Breath Timer 500. Upon receiving the flow indica-
tion signal, blanking 700 begins counting down the
count received from Three-Breath Timer 500 at an
appropriate clock pulse rate received from Clock
and Monitor 200 via line 1207. The length of time
35 required to complete the countdown is the blanking

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1 time represented on graph 1314 of Fig. 13. At the
end of the blanking time, Blanking 700 output via
line 1222 goes on again.

5 Three-Breath Timer [3BT] 500 includes
four pulse counters, each of which receives clock
pulses via line 1206 from Clock and Monitor 200.
In normal operation, at any one point in time,
three of the counters are actively counting pulses
10 while the fourth is delivering its accumulated
count data via databus 1224 to Blanking 700, Flow
Pulse 600, and Seek/Deliver 1100. Three-Breath
Timer 500 advances to the next counter in sequence
when either of inputs received via lines 1218 and
1222 from SCM 400 and Blanking 700 respectively go
15 off. This advancement freezes the count on the
selected counter and resets the formerly selected
counter to enable it to begin counting pulses
again. The selected counter continuously supplies
its count data to databus 1224. Because the
20 counters are selected in sequence, the count on
the selected counter represents the accumulated
count over the three previous breath cycles.

Flow Pulse 600 receives input from SCM
400 via line 1218 and data from 3BT 500 via data-
25 bus 1224. Flow Pulse 600 also receives data in
binary encoded decimal form from the flow rate
selector valve 1940 indicating the prescribed
continuous flow rate. By using the prescribed
flow rate information and the count from the three
30 previous breaths an address, Flow Pulse 600 se-
lects from a read-only-memory (ROM) element a
value (ROM value) which value is also based on the
inhalation-exhalation ratio. This ROM value is
used to convert an input clock pulse received via
35 line 1206 to a ROM frequency. The ROM frequency

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1 is used as the frequency with which to count the
3BT 500 count data received via databus 1224.
Thus, the 3BT data is used by flow pulse 600 for
two purposes: as part of the address for the ROM
5 (in the home embodiment) and as the reference
count for the ROM frequency. When Flow Pulse 600
completes the count, it turns on an output via
line 1226 to FIR 300.

10 Flow Initiation and Rezero 300, upon
receiving the on signal from Flow Pulse 600 via
line 1226, begins the rezeroing cycle. At this
time, the analog output voltage from inhalation
sensor 100 reflects the no-flow condition because
15 sensor 100 is pneumatically isolated from the
patient cannula due to demand solenoid 22 being
de-energized. This sensor 100 voltage is con-
verted to a digital value by a digital-to-analog
converter contained within FIR 300. This voltage
is put in memory by 10 iterations of a successive
20 approximation register, a process which takes
about 11 milliseconds. The reference voltage thus
stored in memory will be used on the next breath
cycle by the comparator as its reference voltage.
In this way, FIR 300 rezeroes during every breath
25 cycle to produce a reference voltage which is very
recent in time which it uses to compensate for any
drift of sensor 100 output voltage.

After rezeroing is complete, FIR 300
provides an on output via line 1228 to SCM 400
30 which enables SCM 400 to re-energize demand sole-
noid 22. This FIR 300 output signal marks the end
of the oxygen pulse shown on graph 1309 of Fig.
13. SCM 400 also turns on output via line 1218 to
3BT 500, but the Blanking 700 signal via line 1222
35 is still off which prevents 3BT 500 from advancing

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1 to the next timer. Blanking 700 disables 3BT 500
via the off status on line 1222. This is done
because at the end of the oxygen pulse, patient
nasal vacuum still exceeds .04 cm. water and the
5 comparator of FIR 300 turns off when sensor 100 is
pneumatically reconnected as demand solenoid 22 is
re-energized. Blanking 700 output via line 1222
goes on at the end of the blanking time which
occurs well into the exhale portion of the patient
10 breath cycle, but by this time the comparator
output of FIR 300 is off and no triggering will
occur until the patient next inhales. Upon the
next inhale, the cycle described above repeats and
continues to do so indefinitely thereby providing
15 a pulse of oxygen near the beginning of the inha-
lation portion of every breath cycle.

Seek/Deliver 1100 is activated upon
detection of an abnormal patient breath rate - for
example, below 8 or above 22 breaths per minute.
20 Seek/Deliver 1100 receives inputs from Clock and
Monitor 200 via line 1206, Reset 800 via line
1212, and 3BT 500 via databus 1224 and produces an
output to SCM 400 via line 1230. Seek/Deliver
1100 compares the count data received from 3BT 500
25 with an internal reference count. If the 3BT 500
count is less than the reference, which indicates
a high breath rate, then Seek/Deliver 1100 turns
on its output for 7 1/2 seconds. Additionally,
Seek/Deliver 1100 uses an internal 7 1/2 second
30 pulse count timer which begins its timing cycle
after the receipt of a signal from Reset 800 via
line 1212 indicating that a valid inhalation has
occurred. If another reset signal is not received
prior to timing out 7 1/2 seconds, which circum-
35 stance indicates a breath rate below 8 per minute,

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1 then Seek/Deliver 1100 turns on the output to SCM
400.

5 The output on signal to SCM 400 causes
it to de-energize both solenoids 22 and 24 for 7
1/2 seconds thereby delivering continuous oxygen
to the patient during this time. At the end of
this 7 1/2 second delivery time, Seek/Deliver 1100
returns to the seek mode and again determines
10 patient breath rate. Seek/Deliver continues
cycling in this way indefinitely; however, at the
end of 97.5 seconds without a valid inhalation
signal (the 97.5 seconds is determined by use of
another internal timer), Seek/Deliver 100 acti-
vates Audible Alarm 1000 via output line 1232.
15 Additionally, Seek/Deliver 1100 provides an output
over line 1232 to Failure Indicator 900 which
illuminates a light emitting diode whenever Seek/
Deliver 1100 is activated. A signal from Reset
800 via line 1234 to Audible Alarm 1000 and Fail-
20 ure Indicator 900 resets Audible Alarm 1000 and
Indicator 900 whenever a valid inhalation is
detected.

Seek/Deliver 1100 also incorporates a 20
second warm-up feature which prevents energizing
25 of solenoids 22 and 24 for this amount of time
after power-up. This is to allow the electronic
components to stabilize before the system goes
on-line.

30 The purpose of the foregoing discussion
is to give a simplified, non-rigorous overview of
the functioning of the primary modules of the
control circuitry 1200. As such, the Fig. 12
block diagram does not show all of the intercon-
nections between components nor does the above
35 discussion explain all of the functions of the

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1 various components. A detailed description and
discussion is provided below in Part II.B.

5 B. Detailed Description of the Elec-
trical Circuitry

The electrical circuits described below
are designed to be powered by a conventional
direct current power supply (not shown) capable of
supplying 12 V.D.C., 8 V.D.C., and 5 V.D.C. In
10 the drawings and discussion the symbol V_{DD} stands
for 5 V.D.C. and the symbol V_{EE} stands for +8
V.D.C.

Additionally, the circuits described
below are of two types - analog and digital. For
15 example, Inhalation Sensor 100 shown in Fig. 1 is
an analog circuit. Flow Initiation and Rezero 300
of Fig. 3 includes both analog and digital compo-
nents which are explained in detail below.

Preferred values of resistors and capa-
20 citors are indicated in parentheses when the
resistor or capacitor is first mentioned, when the
"K" value refers to thousand ohms, and "pf" refers
to picofarads. The circuits of Figs. 2, 4, 5, 6,
7, 8, 9, and 10, and 11 are digital circuits. The
25 digital circuits operate at +5 V.D.C. and when a
particular output, input or signal is described as
being "on" at a state of "one", or "high", this
means +5 V.D.C. When the expressions "off", state
of "zero", or "low" is used, this means 0 V.D.C.
30 A system ground in common use throughout is desig-
nated by the appropriate symbol and the numeral
"6".

The digital circuits described below are
designed for incorporation on one or more semi-
35 conductor chips by the use of conventional tech-

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1 niques using conventional masking cells for gates
and memory elements. As such, the particular
circuit elements such as AND, OR, NAND, NOR gates,
5 inverters, flip-flops, counters and so forth are
conventional devices well known in the art and are
represented by conventional symbols.

 The fact that certain circuits are
designed or designated as digital or analog is not
to be considered as a limitation but rather as the
10 preferred embodiment of the present invention for
reasons including economics, size, power efficiency,
and reliability.

1. Fig. 1, Inhalation Sensor 100

15 Inhalation Sensor 100 includes
pressure sensor 102 which is a conventional device
such as type 176PC14HD22 supplied by Microswitch
Corporation. Pressure sensor 102 includes the
following pneumatic components: diaphragm chamber
20 104, silicon diaphragm 106, restrictor 108, and
pneumatic tubes (dotted lines), 110, 112, 114, and
116. Tubes 110 and 112 pneumatically interconnect
one side of restrictor 108 with one side of dia-
phragm 106 at chamber 112, and both are also
25 interconnected via tube 118 to three-way demand
solenoid 22. Tubes 114 and 116 pneumatically
interconnect the other side of restrictor 108 with
the other side of diaphragm 106 at chamber 104,
and both also interconnect via tube 120 to ambient
30 air. The balance of the pneumatic arrangement
includes oxygen source 18 connected with flow
solenoid valve 20 by representative tube 19,
representaitve tube 21 connects valves 20 and 22,
and the patient cannula 26 is connected via line
35 24 to valve 22 as shown. (See part I above for a

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1 detailed description of the pneumatic system,
discussion here is for the limited purpose of
electrical description). When electrical line 415
energizes the coil of valve 20, valve 20 shifts
5 from the prescription flow orifice to the appropriate high flow orifice (see pneumatic description of part I above). When valve 22 is de-energized, oxygen from source 18 flows via tube 19 through valve 20 and via tube 21 through valve 22
10 and tube 24 to cannula 26. In the de-energized position, valve 22 blocks tube 118. When valve 22 is energized via line 415, tube 21 is blocked and ambient air communicates with cannula 26 via tubes 120 and 114, restrictor 108, tubes 110 and 118,
15 valve 22 and tube 24.

Diaphragm 106 includes a Wheatstone bridge arrangement (not shown) with null and temperature compensation which is implanted on diaphragm 106 by ionization. Power is supplied to
20 the bridge at 8 V.D.C. by line 122 from V_{EE} . Another point of the bridge is grounded by line 124 and ground 6. The output from the bridge exits pressure sensor 102 via lines 126 and 128.

In typical use, the prongs of
25 canula 26 are inserted in the patient's nostrils. Valve 20 is energized and valve 22 is de-energized allowing ambient air communication with cannula 23. When the patient inhales, the nasal vacuum causes the air to flow toward the patient through
30 restrictor 108. The differential pressure created by the air flow through restrictor 108 is transmitted to opposite sides of diaphragm 106 via tubes 110 and 112, and tubes 114 and 116. Because
35 of the direction of the inhale airflow, the lower side (at tube 116) of diaphragm 106 receives the

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1 higher pressure and distorts slightly upwardly.
This distortion of diaphragm 106 also distorts the
resistors of the Wheatstone bridge implanted
thereon which thereby changes the resistance value
5 of one or more the the resistors on the bridge.
This change in resistance value changes the output
voltage across lines 126 and 128. When the pa-
tient exhales, restrictor 108 airflow reverses as
does the distortion of diaphragm 106. Similarly,
10 the bridge resistors also distort, changing the
resistance thereby, and causing a corresponding
output voltage change across lines 126 and 128.

The remaining electrical components
of inhalation sensor 100 provide the means to
15 reference and scale the output voltages of pres-
sure sensor 102 to usable values so that, in this
preferred embodiment, the output of inhalation
sensor 100 nominally ranges from +4.0 V.D.C. at
maximum patient exhalation to +1.0 V.D.C. at
20 maximum patient inhalation with a mid-range value
of +2.4 V.D.C. when there is no flow through
restrictor 108. To accomplish this result, sensor
102 outputs via lines 126 and lines 128 are cou-
pled to the positive inputs of conventional opera-
25 tional amplifiers 130 and 132 respectively.
Amplifier 130 is biased at +8 V.D.C. via line 122
and amplifier 132 is biases to ground 6 via line
134. Amplifier 130 provides an output via line
136 to one side each of resistors 138 (100K) and
30 140 (49.9K). The other side of resistor 138
provides feedback to the negative input of ampli-
fier 130 via line 142 to determine amplifier 130
gain and also couples with one side of resistor
144 (16.2K).
35

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1 Amplifier 132 provides an output
via line 146 to one side of each of resistors 148
(100K) and 150 (49.9K). The other side of resis-
5 tor 148 provides feedback to the negative input of
amplifier 132 via line 152 to determine amplifier
132 gain and also couples with the other side of
resistor 144. Resistor 144 is chosen to have a
value which will give the desired differential of
the output span of inhalation sensor 100.

10 The outputs of amplifiers 130 and
132 are scaled through resistors 140 and 150
respectively and are connected via lines 154 and
156 respectively to the negative input and the
positive input respectively of amplifier 158.
15 Amplifier 158 is biased from V_{EE} at +8 V.D.C. via
line 160 and is referenced to ground 6 by line
162.

 Resistors 164 (10K) and 166 (4.22K)
are interconnected by line 168 to form a voltage
20 divider network coupled between lines 160 and 134.
The voltage produced by this divider at line 168
is coupled to and through resistor 170 to line 156
to bias the positive input of amplifier 158.

 The output of amplifier 158 is
25 transmitted via line 172 to resistor 174 and
output terminal 176. The other side of resistor
174 provides feedback to the negative input of
amplifier 158 by connection with line 154. The
output of the module 100 at terminal 176 is lowest
30 (about 1.0 V.D.C.) when patient inhalation is at a
maximum and highest (about 4.0 V.D.C.) when pa-
tient exhalation is at a maximum.

 The purpose of the particular inhalation
sensor described above is to provide information
35 concerning the breath cycle of the patient and is

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1 preferred for many reasons including sensitivity,
reliability, cost and so forth. One skilled in
the art will readily appreciate that other devices
would perform equivalently. For example, the
5 particular device could be used in a pressure
sensing configuration by dead-ending line 118 at
chamber 104 and eliminating restrictor 108. Also,
for example, a "hot-wire" anemometer could be used
in place of device 102 to provide patient breath
10 cycle data.

2. Fig. 2, Clock and Monitor 200

Clock and Monitor 200 includes
oscillator 201, clock monitor 202 and clock 203.
15 Oscillator 201 is a conventional Colpitts oscil-
lator with a ceramic oscillating element which
generates a 4 megahertz square wave signal between
0 and +5 volts D.C. having a 50% duty cycle. The
signal from oscillator 201 is transmitted to clock
20 monitor 202 and clock 203 via line 204.

Clock and monitor 202 includes two
conventional three-state devices 205 and 206 which
in the application herein provide for rapid
switching operations because of their characteris-
25 tics of providing a low input impedance when
enabled and a high input impedance when not en-
abled. Each device 205 and 206 receives a con-
stantly on supply voltage V_{DD} via line 207.
Device 205 receives the 4 megahertz signal from
30 oscillator 201 via line 204 at its operating
enable [OE] terminal.

When device 205 receives the +5
V.D.C. (i.e. "up" or "on") portion of the 4 mega-
hertz square wave received via line 204 at the OE
35 terminal, supply voltage is transmitted from line

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1 207 through to the output of device 205. When the
input at OE is off, the output of device 205 is
off. The output from device 205 is transmitted
5 via line 208 to capacitor 209 (33 pf.), the other
side of which is connected to ground 6 via line
210, to resistor 211 (100K), the other side of
which is connected to ground 6 via line 212, and
to Schmitt-trigger NAND gate 213. Device 205
10 charges capacitor 209 when the output of device
205 is on during the on portion of the oscillator
signal. When device 205 is off during the off
portion of the oscillator signal, capacitor 209
discharges through resistor 211. The values of
15 capacitor 209 and resistor 211 are chosen such
that the exponential decay of capacitor 209
through resistor 211 during the time device 205 is
off does not fall below the trigger level of NAND
213 (assuming a normal, as designed, oscillator
signal).

20 The operation of three state device
206 is similar to that of device 205 except that
the OE terminal of device 206 is supplied with the
oscillator signal via inverter 215 and line 204.
Because of inverter 215, device 206 is exactly out
25 of phase with device 205 so that the output of
device 206 is on during the off portion of the
oscillator signal and is on during the off portion
of the oscillator signal. The output from device
206 is transmitted via line 216 to capacitor 217
30 (33 pf.), the other side of which is coupled to
ground 6 via line 218, to resistor 219 (100K), the
other side of which is coupled to ground 6 via
line 220, and to the second input to NAND 213.
The output from device 206 charges up capacitor
35 217 during the off portion of the oscillator

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1 signal. Device 206 is off during the on portion
of the oscillator signal and during this time
capacitor 217 discharges through resistor 219 to
5 ground. Capacitor 217 and resistor 219 have the
same values as capacitor 209 and resistor 211
respectively and the exponential decay of capaci-
tor 217 through resistor 219 is such that normally
the value does not fall below the Schmitt-trigger
value of NAND 213.

10 During normal operation, the output
of NAND 213 is normally off because the inputs via
lines 208 and 216 never fall below the Schmitt-
trigger value of about 3 V.D.C. However, if an
15 abnormality would develop in the signal from
oscillator 201, one or the other of the inputs via
lines 208 and 216 to NAND 213 will go off. For
example, if the oscillator fails so that its
output is continually on and not oscillating
anymore, then the output from device 206 will be
20 off, and NAND 213 will be on. If for example the
signal from oscillator 201 goes off and stays off,
then the output from device 205 will be off and
the output from NAND 213 will then be on. If the
oscillation frequency of oscillator 201 decreases
25 significantly capacitors 209 and 217 will dis-
charge through resistors 211 and 219 respectively
to values below the Schmitt-trigger level of NAND
213 before being charged up again and the output
from NAND 213 will go on. If the oscillation
30 frequency of oscillator 201 goes too high, capaci-
tors 209 and 217 will not become sufficiently
charged and their value will decrease during
discharge through resistor 211 and 219 respective-
ly to values below the Schmitt-trigger value of
35 NAND 213. Thus, any number of abnormalities in

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1 the signal from oscillator 201 will cause the
output from NAND 213 to turn on. The output from
NAND 213 is transmitted via line 221 to output
terminal 222.

5 Clock 203 is designed to provide a wide-
range of specific outputs to supply the various
subcircuits. This result is accomplished by
scaling the 4 megahertz signal from oscillator 201
through various pulse counter circuits. For the
10 sake of clarity, the following discussion assumes
that all counters have been initially reset at the
"R" terminal on each.

The Clock 203 first performs a
division by 2 on the 4 megahertz signal from
15 oscillator 201 received over line 204. This is
accomplished using a conventional "D" flip-flop
with reset 223. Flip-flop 223 includes clock
terminal C, data terminal D, reset terminal R, and
output terminals Q and \bar{Q} . Flip-flop 223 receives
20 a reset signal at R via line 224. \bar{Q} is connected
to D via line 225 and flip-flop 223 produces its
output at Q. Flip-flop 223 receives the 4 mega-
hertz square wave signal from oscillator 201 via
line 204 at terminal C. Initially, Q is off and \bar{Q}
25 is on. At the first clock pulse at C, Q goes on
by virtue of the on signal received at D (\bar{Q} being
on when Q is off and vice versa) and \bar{Q} goes off.
At the second clock pulse at terminal C, Q goes
off because of the off signal at terminal D. At
30 this time \bar{Q} goes on and flip-flop 223 is back to
its initial state. This cycle continues so that Q
goes on with every other input pulse received at
terminal C. In this way flip-flop 223 performs a
scale division by 2 of the input received at C and
35

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1 the output of flip-flop 223 at Q is a 2 megahertz square wave signal with a 50% duty cycle.

Conventional "D" flip-flop with
5 reset 226 also performs a division by two scaling operation. Flip-flop 226 includes clock terminal C, data terminal D, reset terminal R, and output terminals Q and \bar{Q} . Flip-flop 226 receives the 2 megahertz output from flip-flop 223 via line 227 at terminal C and can receive a reset signal at
10 terminal R via line 224. Terminal \bar{Q} is connected to terminal D via line 228. In an operation the same as that of flip-flop 223, flip-flop 226 performs a division by two scaling operation so that the two megahertz signal received at terminal
15 C is scaled to produce a one megahertz 50% duty cycle output at terminal Q of flip-flop 226. This output is transmitted via line 229 to counter 230.

Counter 230 in combination with
20 NAND gate 231 scales the one megahertz signal from flip-flop 226 down to a 100 kilohertz downpulse square wave signal. Counter 230 is a conventional binary decade counter which automatically resets itself to zero upon reaching a binary count of decimal ten. Counter 230 includes enable terminal
25 EN, clock terminal C, reset terminal R, least significant bit terminal Q_0 , and most significant bit terminal Q_3 . (Terminals for bits Q_1 and Q_2 are not shown.) A continuously on enable signal is received at terminal EN via line 207 which is
30 supplied by V_{DD} . A reset signal can be received at terminal R via line 224. The one megahertz square wave signal from flip-flop 226 is received at terminal C via line 229. Counter 230 provides
35 outputs at terminals Q_0 and Q_3 via lines 232 and 232a respectively to NAND gate 231. In operation,

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1 counter 230 starts with bits Q_0 - Q_3 at a state of
zero. The output from NAND 231 is on and stays on
until a count of nine is registered on counter
230. Upon reception of the ninth clock pulse at
5 C, bits Q_0 and Q_3 , representing a binary count of
decimal nine, both go on and NAND 231 output goes
off. At the tenth input clock pulse, counter 230
resets all bits back to zero and NAND 231 output
goes on. The cycle then repeats with NAND 231
10 output going off during one input pulse out of
every ten. Thus, the incoming one megahertz
square wave signal is converted to an output
signal via line 233 to a 100 kilohertz down-pulse
square wave signal with a 10% duty cycle. This
15 100 kilohertz signal is transmitted to counter 234
and inverter 235 via line 233. Inverter 235
converts the incoming signal to a 100 kilohertz up
pulse with a 10% duty cycle which is transmitted
via line 236 to output terminal C5.

20 Counter 234 in combination with
NAND gate 237 scales its incoming 100 kilohertz
signal to a 10 kilohertz signal. Counter 234 is
identical to counter 230 and includes terminals
EN, C, R, Q_0 , and Q_3 . Terminals Q_1 and Q_2 are not
25 shown. Counter 234 receives a continuously on
enable signal at terminal EN via line 207. Coun-
ter 230 can receive reset input at terminal R via
line 224 and receives the 100 kilohertz downpulse
signal via line 233 at terminal C. NAND 237
30 receives inputs from Q_0 and Q_3 via lines 238 and
238a respectively. Counter 234 operates on the
rising edge of the input signal received at C and
adds one binary count each time an arriving pulse
is received at terminal C. As with counter 230,
35 234, Q_0 and Q_3 go on only when a count of nine is

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1 registered. Upon the tenth pulse received at
terminal C all bits of counter 234 are reset to
zero. The output of NAND 237 is thus a ten kilo-
hertz downpulse with a 10% duty cycle. This
5 output is transmitted via line 237a to counter
239, terminal C6, and inverter 237b. Inverter
237b converts the incoming signal to a ten kilo-
hertz up pulse signal with a 10% duty cycle which
is transmitted to terminal C7 via line 240.

10 Counter 239 is a binary decade counter
identical to 230 and 234 but with which the out-
puts from all four bits are used. Counter 239
includes enable terminal EN, clock input terminal
C, reset terminal R, and output bit terminals Q_0 ,
15 Q_1 , Q_2 , and Q_3 with bit Q_0 being the least signi-
ficant bit and Q_3 being the most significant bit.
Counter 239 receives a continuously on enable
signal at terminal EN via line 207, can receive a
reset signal in terminal R via line 224, and
20 receives the ten kilohertz signal from NAND 237 at
terminal C. Counter 239 provides outputs at Q_0 ,
 Q_1 , Q_2 , Q_3 , via lines 240a, 240b, 240c, and 240d,
respectively. The output of Q_0 via line 240a is
transmitted to inverter 241a and NAND gate 242.
25 The output of Q_1 is transmitted via line 240b to
AND gate 243a, inverter 241b, and to AND gate
243c. The output of terminal Q_2 is transmitted
via line 240c to inverter 241c and AND gate 243c.
The output of terminal Q_3 is transmitted via line
30 240d to AND 243d and AND 242. The output of
inverter 241a is transmitted via line 244a to AND
243a, AND 243b, AND 243c, and AND 243d. The
output from inverter 241b is transmitted via line
244b and AND 243b. The output from inverter 241c
35 is transmitted via line 244c to AND 243a. The

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1 outputs from AND gates 243a-d are transmitted via
lines 245a, b, c, and d respectively to terminals
C1, C2, C3, and C4, respectively.

5 The purpose of counter 239 along
with inverters 241a-c and AND gates 243a-d is to
provide a series of non-overlapping one kilohertz
up pulse signals. Counter 239 counts the incoming
ten kilohertz downpulses received at terminal C.
10 The pulse count is represented in binary at termi-
nals Q_0 - Q_3 . Inspection of the connections of AND
243a reveals that it provides an on output to
terminal C1 only when its three inputs are on, and
this occurs only when a count of two exists on
counter 239. That is, the output to terminal C1
15 is only if Q_0 is off, Q_1 is on, and Q_2 is off. In
four bit binary these conditions also would be
satisfied at a decimal count of 12, but because
binary decade counter 239 resets itself upon
reaching a count of ten, these conditions are
20 never reached, and thus C1 only comes on a count
of two, which occurs once every ten input pulses
at terminal C.

By similar analysis, the output at
C2 is on only when a count of four exists on
25 counter 239, that is when Q_0 and Q_1 are off and Q_2
is on. A count of four exists for only one pulse
duration out of every ten in the operation of
counter 239. Thus the output of C2 is on only for
one pulse width out of every ten.

30 The output at terminal C3 is on
only when a count of six exists on counter 239.
That is, when Q_0 is off and Q_1 and Q_2 are on.

The output at C4 is on only if a
count of 8 exists on counter 239. That is, when
35 Q_0 is off and Q_3 is on. When Q_0 comes back on at

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1 a count of nine, AND 243d is no longer satisfied
and C4 is off. Thus as with terminals C1, C2, and
C3 the output at C4 is on only for one incoming
5 pulse duration out of every ten. The overall
effect of this arrangement is that a one kilohertz
up pulse square wave output exists at terminal C1,
C2, C3, and C4 with 10% duty cycles, but these
outputs are non-overlapping.

10 The output from NAND 242 is off
only if a count of nine exists on counter 239. At
all other pulse counts the output from NAND 242 is
on. Thus the output of NAND is a one kilohertz
downpulse with a 10% duty cycle. This output is
15 transmitted via line 246 to counter 247, terminal
C8 and inverter 248. Inverter 248 converts the
incoming one kilohertz downpulse signal to a one
kilohertz up pulse signal which is transmitted to
terminal C9 via line 249.

20 Counter 247 is identical to coun-
ters 230 and 234 and is used in the same way to
scale by a factor of ten the incoming one kilo-
hertz downpulse to a 100 hertz output downpulse.
Counter 247 receives a continuously on enable
25 signal via line 207 at terminal EN, can receive
reset signal at terminal R via line 250 from
terminal 840, and receives the one kilohertz
downpulses from NAND 242 at terminal C via line
246. Terminals Q_0 and Q_3 are connected to NAND
251 via lines 252 and 252a respectively. Termi-
30 nals Q_0 and Q_3 are both on only when a count of
nine exists on counter 247 which occurs only once
every ten input cycles as with counters 230 and
234. Thus the output from NAND 251 is a 100 hertz
square wave downpulse signal with a 10% duty
35 cycle. The output from NAND 251 is transmitted

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1 via line 253 to counter 254, output terminal C10,
inverter 255, inverter 256 and counter 257. In-
verter 255 converts the incoming 100 hertz down
5 pulse signal from NAND 251 to a 100 hertz up pulse
signal which is delivered to terminal C11 via line
258.

Counter 254 is identical to coun-
ters 230, 234, and 247 and is used in the same way
10 to scale the incoming clock pulse by a factor of
ten. Counter 254 receives a continuously on
enable signal via line 207 at terminal EN, re-
ceives a 100 hertz clock signal from NAND 251 at
terminal C, and can receive a reset signal at
15 terminal R from OR gate 259 via line 260. OR gate
259 receives its first input via line 250 from
terminal 840 and the second input via line 261
from terminal 347.

Outputs from Q_0 and Q_3 of counter
254 are transmitted to NAND 262 via lines 263 and
20 263a respectively. The output from NAND 262 is
off only when the count of nine exists on counter
254. Thus the output of NAND 262 is a ten hertz
square wave downpulse with a 10% duty cycle which
is transmitted via line 264 to terminal C15 and
25 inverter 265. Inverter 265 converts the 10 hertz
downpulse signal to a ten hertz up pulse signal to
terminal C12 via line 266.

The next clock scaling circuit is
designed to convert 100 hertz downpulses to 10
30 hertz up pulses at terminal C13. Input 100 hertz
downpulses delivered to inverter 256 are converted
to 100 hertz up pulses and transmitted via line
267 to counter 268 and inverter 269.

Counter 268 is a conventional eight
35 bit Johnson counter and includes enable terminal

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1 CE, reset terminal R, clock terminal C, and output
bit terminal Q₅. (Terminals for bits Q₀, Q₁, Q₂,
Q₃, Q₄, Q₆, and Q₇ are not shown.) Terminal CE is
5 clamped to ground 6 via line 268A which by means
of an internal inverter continuously enables
counter 268 to count input pulses. Incoming 100
hertz up pulses are received at terminal C via
line 267. At the fifth incoming clock pulse at
10 terminal C, Q₅ goes on which output is transmitted
via line 270 to terminal Cl3 and NAND 271.

Inverter 269 converts the 100 hertz
up pulse signal received via line 267 to a 100
hertz downpulse signal which it transmit via line
272 to NAND 271. NAND 271 output goes off when Q₅
15 is on and a the end of incoming clock signal via
line 272 when the signal goes back on. When both
inputs to NAND 271 are satisfied, NAND output 271
goes off which output is transmitted via line 273
to NAND 274. The other input to NAND 274 is
20 received via line 275 from terminal 838. The
input from terminal 838 is normally on except when
a reset condition exists. The output from NAND
274 is transmitted to R of counter 268 via line
276. When the input to NAND 274 via line 273 goes
25 off, the output from NAND 274 goes on and resets
counter 268. As soon as counter 268 is reset, Q₅
goes off, NAND 271 is no longer satisfied and its
output goes on to NAND 274. At this point both
inputs to NAND 274 are on and the output of NAND
30 274 goes off to remove the reset signal from R of
counter 268. This cycle repeats continually so
that Q₅ comes on for one input pulse cycle dura-
tion out of every five received at terminal C and
the incoming 100 hertz signal is thus scaled to a
35 20 hertz up pulse signal with a 20% duty signal
which is delivered via line 270 to terminal Cl3.

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1 The last scaling circuit in clock
203 converts the 100 hertz downpulses from NAND
251 to up pulses at approximately 4.16 hertz at
terminal C14. The final scaling process starts
5 with conventional eight-bit Johnson counter 257
which includes clock enable terminal CE, reset
terminal R, clock input terminal C, bit output
terminal Q_0 , and bit output terminal Q_7 . Output
terminals for bits 1, 2, 3, 4, 5, and 6 are not
10 shown. Divider 257 receives 100 hertz downpulses
at terminal C via line 253. Initially, divider
257 is reset with all bits except Q_0 at zero and
the input to CE via line 276 is off; by means of
an internal inverter, divider 257 is enabled to
15 count incoming clock pulses when CE input is off.
At the first clock pulse input, Q_0 goes off which
output is transmitted via line 277 to reset divider
278. Divider 257 continues to clock through
clock pulses and upon receiving the seventh clock
20 pulse, Q_7 goes on which output is transmitted via
line 276 to terminal CE and to AND gate 279. The
other input to AND 279 is the 100 hertz downpulse
signal received via line 253. As soon as this
clock signal goes back on, which is the end of the
25 pulse, then both inputs to AND 279 are on and the
output of AND 279 goes on, which output is transmitted
via line 280 to divider 278. When Q_7 of
divider 257 goes on, this disables divider 257 via
line 276 to terminal CE and causes it to hold the
30 Q_7 output on.

 Divider 278 is identical to divider
257 and is likewise a conventional eight-bit
Johnson counter. Divider 278 includes enabling
terminal CE, reset terminal R, clock input terminal
35 C, and sixth bit output terminal Q_6 . (Termi-

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1 nals for bits Q_1 , Q_2 , Q_3 , Q_4 , Q_5 , and Q_7 are not
shown.) Terminal CE is clamped to ground 6 via
line 281 and thus continuously enabled. Terminal
5 R can receive a reset input via line 277 from
terminal Q_0 of divider 257. Terminal C receives
its input via line 280 from AND 279.

Clock pulses received by AND 279
via line 253 transmit on through AND 279 because
the other input to AND 279 is from Q_7 of divider
10 257 which is held on until divider 257 is reset
later in the sequence. The clock pulses passing
through AND 279 via line 280 are received at
terminal C of divider 278 when Q_7 of divider 257
goes on. Upon reception of the sixth rising edge
15 clock pulse by divider 278, terminal Q_6 goes on.
This on output from Q_6 is transmitted via line 282
to flip-flop 283 and to NAND 284.

Inverter 285 receives clock pulses
via line 253 and upon reception of the very next
20 off pulse, the output of inverter 285 goes on
which output is transmitted to NAND 284 via line
286. At this point both inputs to NAND 284 are
on and NAND 284 output goes off. The off output
of NAND 284 is received by NAND 287 via line 288.
25 The other input to NAND 287 is an input from
terminal 838 via line 275 which is normally on
unless a reset condition exists. Because the
output to NAND 287 via line 288 is off, the output
of NAND 287 goes on to reset terminal R of divider
30 257 via line 289. With divider 257 thus reset, Q_7
goes off which removes the signal from terminal CE
and enables divider 257 to again count clock
pulses. Also, when Q_7 goes off, AND 279 goes off
and divider 278 no longer receives clock pulses
35 and Q_0 of divider 257 goes on to reset divider
278.

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1 The interconnections described
above effectively interconnect dividers 257 and
278 into a 12 bit divider so that an output from
5 Q_6 of divider 278 occurs once for every 12 pulses
of the 100 hertz signal received by divider 257.

 Flip-flop 283 is a conventional "D"
type flip-flop with reset and is used to scale the
incoming signal by a factor of two and is identi-
cal to flip-flops 223 and 226 which were used for
10 the same purpose. Flip-flop 283 can receive a
reset signal via line 290 from inverter 291 which
receives its input via line 275 from input ter-
minal 838. Because of inverter 291, the reset
signal on line 290 is normally off unless a reset
15 condition exists. Terminal C receives its input
via line 282 from terminal Q_6 of divider 278.
Terminal D receives its input via line 292 from
terminal \bar{Q} . Terminal Q provides its output via
line 293 to terminal C14 and flip-flop 283 scales
20 the incoming clock pulses received at C by a
factor of two. Dividers 257 and 278 as combined
with flip-flop 283 scale the incoming 100 hertz
downpulses by a factor of 24 so that the output at
terminal C14 is at a frequency of 4.16 hertz with
25 a 50% duty cycle.

3. Fig. 3, Flow Initiation and Rezero-
ing 300

 Flow Initiation and Rezeroing
30 module 300 broadly includes rezeroing section 301
and flow initiation section 302. The broad
function of flow initiation 302 is to detect
patient inhalation, validate that inhalation, and
provide an output signal when a valid inhalation
35 is detected.

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1 Flow Initiation 302 begins its
function with comparator 306 which is a conven-
tional differential operational amplifier having a
5 positive input terminal (+), negative input termi-
nal (-), and an output. Comparator 306 receives a
positive input signal via line 308 from terminal
176 which is the output from inhalation sensor
100. Comparator 306 receives a negative input
10 from digital-analog converter [DAC] 310, which is
part of rezeroing section 304, via line 312. The
output from DAC 310 via line 312 is a reference
voltage equal to the voltage output of inhalation
sensor 100 at terminal 176 during the previous
15 breath cycle when solenoid valve 22 was de-ener-
gized and no air flow was occurring through re-
strictor 108. When the positive terminal input
voltage is greater than the negative terminal
input voltage to comparator 306, then comparator
20 306 output is on. This is the status existing
when patient inhalation is not occurring, that is,
when the patient is exhaling, at pause, or when
the patient's inhale nasal vacuum is less than .04
cm. water. When the positive terminal input
voltage is less than the negative terminal input
25 voltage, then the output of comparator 306 is off.
This situation exists when the patient is inhaling
and nasal vacuum exceeds .04 cm. water. Compara-
tor 306 is used in a "negative trigger" mode so
that patient inhalation causes comparator 306
30 output to go off, which triggers the remainder of
flow initiation section 302.

 Comparator 306 output is biased in
order to provide a proper digital voltage. This
is accomplished by supplying one side of resistor
35 314 (100K) with biasing voltage V_{DD} (+ 5 V.D.C.)

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1 via line 316. The other side of resistor 314 is
connected via line 318 to inverter 320 and the
resistor 322 (1K). The resistor 322 is connected
via line 324 to the output of comparator 306.

5 When comparator 306 output is on
(indicating no inhalation is occurring), then the
output of inverter 320 is off, which output is
transmitted via line 326 to serial register 328
and inverter 330. Because the input to inverter
10 330 is off, its output is on via line 332 to OR
gate 334. By virtue of the on input via line 332,
OR 334 output is on via line 335 to the reset
terminal R of register 328. Thus, lack of patient
inhalation causes a continuous on signal to hold
15 register 328 in a reset condition.

When inhalation occurs (i.e., when
patient nasal vacuum exceeds .04 cm. water), com-
parator 306 output goes off, inverter 320 output
goes on, and inverter 330 output goes off, which
20 removes the reset signal from register 328. Also
when inverter 320 output goes on, terminal D of
register 328 receives this on signal via line 326.

Register 328 is a conventional ten
bit serial register which successively transfers
25 input data from the first to the last bit with
each incoming clock pulse. Register 328 includes
data input terminal D, reset terminal R, clock
input terminal C, and tenth bit output terminal
Q₉. Output terminals for bits Q₀ through Q₈ are
30 not shown because they are not used. Terminal C
receives one kilohertz up pulses from terminal C9
via line 336.

The purpose of register 328 is to
provide a ten millisecond delay upon the occur-
35 rence of patient inhalation to insure that the

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1 inhalation signal is not a spurious event; the ten
millisecond delay thereby validates inhalation
detection. The clock pulses received at terminal
C occur at a rate of one per millisecond and the
5 on data signal received at terminal D thereby
clocks through the ten bits at a rate of one per
millisecond so that after ten milliseconds Q_9 goes
on. If at any time during the ten milliseconds
comparator 306 output goes on, then register 328
10 will receive a reset signal at R via inverters 320
and 330 and OR 334 which occurrence resets all the
bits of register 328 thereby preventing any output
signal at Q_9 .

15 If comparator 306 output is off for
the required ten milliseconds, then, at the end of
this time, Q_9 goes on to provide an input to AND
337 via line 338. At this point in the cycle,
inverter 339 output is on via line 340 to AND gate
20 337, and AND 337 output goes on via line 341 to
"S" flip-flop 342.

Conventional "S" flip-flop with
reset 342 includes reset terminal R, data set
terminal S, and output terminal Q (\bar{Q} is not shown
because it is not used). When terminal S receives
25 an on input via line 341, then Q goes on, which
output is transmitted via line 343 to out put
terminals 344, 345, 346, and 347.

When the Q on output from flip-flop
342 is detected by Three Breath module 500 via
30 Solenoid Control module 400, Three Breath 500
turns off its output to terminal 506 which is
transmitted via line 349 to "D" flip-flop 350 of
flow initiation 302. (The details of this feed-
back from Three Breath 500 will be explained in
35 detail below.) Flip-flop 350 is a conventional

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1 "D" type flip-flop with set and reset and includes
data-input terminal D, set terminal S, clock input
terminal C, and output terminal Q (\bar{Q} is not
5 shown). Terminal C receives one kilohertz down-
pulse clock signals from terminal C8 via line 351.
The trailing (rising) edge of the downpulse re-
ceived at terminal C triggers flip-flop 350 to
transfer the off data signal at D to output termi-
10 nal Q. The initial state of flip-flop 350 is set
by an input to terminal S from circuit input
terminal 834 via line 353 which also supplies
inverter 354.

The off output of flip-flop 350 is
transmitted via line 355 to NAND gate 356. The
15 other input to NAND 356 is supplied via line 357
from inverter 354. At this point in the cycle,
the input to inverter 354 is off so that the
output is on; however, when the input to NAND 356
from flip-flop 350 goes off, the output of NAND
20 goes on which is transmitted via line 358 to
flip-flop 342, inverter 339 and OR gate 359. When
NAND 356 output goes on this resets flip-flop 342
at terminal R causing output Q to go off, which
causes the output from inverter 339 to go off,
25 which causes AND 337 output to go off, and resets
register 328 via OR 359, line 360, OR 334, and
line 335 to terminal R of register 328.

At this point in the cycle the
output of inverter 361 via line 362 to OR 359 is
30 off because the input to inverter 361 received via
line 363 is on.

To sum up the operation of flow
initiation 302, when sufficient patient inhalation
occurs, comparator 306 goes off, which removes the
35 reset signal from terminal R of register 328 at

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1 which point it begins clocking through the on data
input signal. At the end of ten milliseconds the
output from register 328 goes on, which is trans-
mitted through AND 337 to flip-flop 342. The
5 output from 342 is transmitted to various circuit
components including the Three Breath module 500,
which sends back a signal to turn off flip-flop
350, the off output from which then causes NAND
356 to go on, which resets flip-flop 342 and
10 register 328. The net effect is that the output
of flip-flop 342 is a single up pulse.

Rezeroing section 304 performs two
main operations. First, DAC 310 supplies a re-
ference voltage via line 312 to comparator 306.
15 Secondly, rezeroing 304 updates its reference
signal by putting a new signal in memory for use
during the succeeding breath cycle.

Rezeroing 304 includes a conven-
tional ten bit successive approximation register
20 [SAR] 364. SAR 364 includes output data terminals
 Q_0 , Q_1 , Q_2 , Q_3 , Q_4 , Q_5 , Q_6 , Q_7 , Q_8 , Q_9 , which
correspond to the ten bits of SAR 364, with Q_0
being the least significant bit and Q_9 being the
most significant bit. SAR 364 also includes an
25 end-of-conversion terminal EOC, whose output is on
and is applied via line 363 to inverter 361 and
output terminal 333 after a successful analog-to-
digital conversion has occurred; that is, terminal
EOC is normally on except when SAR 364 is under-
30 going the conversion iterations.

Input terminal SC is the start con-
version terminal, which initiates the analog to
digital conversion process whenever terminal SC
receives an input via line 365. An on signal at
35 terminals 825 or 684 is transmitted via lines 368

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1 and 369 respectively to OR 370, whose output is
transmitted via line 371 to OR 372, whose output
on line 365 terminates at terminal SC. OR 372
5 also receives an input from terminal 1158a via
line 374.

Terminal OR (overrange) of SAR 364
provides an on signal corresponding to an over-
range condition of SAR 364. This overrange signal
is transmitted via line 375 to terminal 376 and
10 inverter 377. The output from inverter 377 is
transmitted via line 378 to terminal 379.

Non-overlapping one kilohertz up
pulse clock signals are received via lines 380a,
380b, 380c, 380d, from terminals C1, C2, C3 and
15 C4, respectively. SAR 364 also includes an input
terminal labeled DATA at which SAR 364 receives
input data voltage corresponding to the analog
voltage to be put in the ten bit memory.

Digital-to-analog converter 310 is
20 a conventional ten-bit type which receives bit
data from SAR 364 corresponding respectively to
bits Q_0 - Q_9 through lines 381a, 381b, 381c, 381d,
381e, 381f, 381g, 381h, 381i, and 381j respec-
tively. DAC 310 also includes output terminal OUT
25 through which DAC 310 conveys its analog voltage
output signal via line 312 to comparator 306.

Rezeroing 304 puts new data in the
memory of SAR 364 near the end of each flow pulse.
When the Flow Pulse module 600 completes the
30 timing of an oxygen pulse (to be explained in more
detail below), Flow Pulse 600 produces an on
signal at terminal 684, which signal is received
at terminal SC of SAR 364, which starts the con-
version process. At this time the output from
35 terminal EOC goes off which prevents solenoid 22

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1 from being de-energized. Because solenoid 22
remains energized, no air is flowing through
restrictor 108 (Fig. 1) and the output from inha-
5 lation sensor 100 at terminal 176 represents a
no-flow reference voltage.

Analog comparator 382 (a conventional
differential operational amplifier) is central to
the conversion process and receives the no-flow
voltage signal from inhalation sensor 100 via line
10 308 at its positive input terminal. Analog com-
parator 382 receives DAC 310 output via line 312,
resistor 383 (27.4 ohms), and line 384 at the
negative input terminal. The value of resistor
15 383 is calculated to bias the DAC 310 output
signal so that the value put in SAR 364 memory
corresponds to inhalation sensor 100 voltage
output signal existing when a patient nasal vacuum
is .04 cm. water. The negative terminal input
20 voltage to comparator 382 is also biased to a
chosen mid-range value by way of voltage V_{EE} (+8
V.D.C.) connected via line 385 to resistor 386
(20K). The other side of resistor 386 is con-
nected to the negative input terminal of compara-
tor 382 by line 384.

25 The output of comparator 382 is
biased to provide the proper analog voltage to
inverter 387 by applying voltage V_{DD} (+5 V.D.C.)
via line 388 to resistor 389 (100K) and from the
other side of resistor 389 via line 390 to resis-
30 tor 391 (1K). Resistor 391 is also connected to
the output of comparator 382 by line 392. Resis-
tor 389 is also coupled to the input inverter 387
by line 390. The output of inverter 387 is con-
35 nected via line 393 to inverter 394 whose output
is connected via line 395 to the DATA terminal of
SAR 364.

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1 When the SAR 364 conversion process
begins, data received at the DATA terminal of SAR
364 begins clocking through with each pulse re-
5 ceived from terminals C1-4, starting with the most
significant bit Q_9 . The clock pulses received at
terminal C1-4 are non-overlapping to insure dis-
crete sequencing of data transmission from one bit
to the next. During the conversion process, if
10 the input to the positive terminal of comparator
382 is greater than the input received at the
negative terminal, then the comparator is on and
via inverters 387 and 394, the DATA input to SAR
364 is one. If the voltage signal received at the
15 positive terminal is less than the voltage re-
ceived at the negative terminal of the comparator
382, then the DATA input to SAR 364 is a zero.
Thus, the greatest output voltage from DAC 310
exists when all bits are one. If the feedback to
20 comparator 382 from DAC 310 is greater than the
voltage from inhalation sensor 100 then the data
input to SAR 364 for that bit is zero. This
sequence continues until all ten bits receive a
data input. At this point the analog data is in
25 memory and the EOC terminal goes on signalling the
end of conversion, which allows solenoid 22 to
re-energize to end the oxygen pulse.

4. Fig. 4, Solenoid Control and Monitor

30 400

Solenoid Control and Monitor module
400 has two main purposes. The first purpose is
to energize and de-energize the solenoid coils of
solenoid valves 20 and 22. The second purpose is
35 to monitor the status of the coils in conformity
with the control signals and to provide output

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1 signals if no abnormality exists. In the hospital
use of the present invention two solenoid valves
20 and 22 are used; however, in the home version,
5 solenoid valve 20 is not present. The description
that follows in this section is for the more
complicated hospital version.

Solenoid Control and Monitor 400
receives a flow initiation signal at terminal 344,
10 which is the output of Flow Initiation and Rezero-
ing module 300, and which signal indicates that a
valid inhalation has occurred. This signal is
transmitted via line 401 to flip-flop 402 which is
a conventional "S" flip-flop with reset and having
15 a set function terminal S, a reset terminal R, and
an output terminal \bar{Q} . (Output terminal Q is not
shown because it is not used.) When terminal S
receives the on signal via line 401, \bar{Q} goes off,
which output is transmitted via line 403 to output
20 terminal 404 and AND gate 405. When line 403 goes
off, AND 405 goes off via line 406 to AND 407,
which output also goes off via line 408 to OR 409,
inverter 410 goes off, inverter 410 output goes on
via line 412 to inverter 413 and AND gate 414.
25 When the input to inverter 413 goes on, the output
from inverter 413 goes off via line 415 to current
limiting resistor 416 (100K) and terminal 415a.
The other side of resistor 416 is connected via
line 417 to the gate of field effect transistor
30 [FET] 418. With the gate to FET 418 de-energized,
solenoid coil 419 associated with solenoid valve
22 is de-energized and solenoid valve 22 allows
oxygen to flow to the patient.

The source S of FET 418 is clamped
35 to ground 6 via line 420. The drain of FET 418 is
connected via line 421 to the anode of diode 422,

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1 one side of solenoid coil 419, and resistor 423
(4.02K). The other side of resistor 423 is
clamped to ground 6 via line 425.

5 The cathode of diode 422 is con-
nected via line 427 to the other side of solenoid
coil 419, capacitor 427a (68 micro f.) the other
side of which is clamped to ground 6 via line
427b, and to current limiting resistor 428 (100
10 ohms). Operating voltage at 12 V.D.C. is supplied
to the other side of resistor 428 via line 429.
Diode 422 serves to limit surge current through
FET 418 when solenoid coil 419 is de-energized.
Capacitor 427a provides a "snap" to quickly ener-
gize coil 419.

15 Briefly then, the reception of an
on signal at terminal 344, which indicates that
valid inhalation has occurred, causes solenoid
coil 419 to be de-energized thus allowing oxygen
to flow to the patient. This marks the beginning
20 of the oxygen flow pulse.

Flip-flop 402 keeps \bar{Q} off until a
reset signal is received at terminal R via line
430 from OR 431. The output of OR goes on when it
receives an on signal via line 432 from terminal
25 834 or via line 433 from terminal 687. Terminal
834 is on only if a reset condition exists and is
thus normally off. An on signal is received at
terminal 687 when Flow Pulse Circuit module 600
completes the timing out of the oxygen pulse. At
30 this time flip-flop 402 receives a reset signal at
terminal R and \bar{Q} goes on. However, AND 405 is not
yet satisfied because it has not yet received an
end of conversion signal from terminal 333 via
line 434 indicating that successive approximation
35 register 364 of Flow Initiation and Rezeroing

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1 module 300 has completed its conversion of the new
analog signal.

5 The input to AND 405 via line 435
from terminal 1127 is normally on unless an abnormality exists. Similarly, the input via line 437
is normally on also unless an abnormality is
detected by the solenoid monitor. Thus, inputs to
AND 405 via lines 437, 403, and 435 are on, but
10 the input via line 434 is off until the end of
conversion state of shift approximation register
364. When the input via line 434 goes on, AND 405
output goes on to AND 407. AND 407 input via line
440 is normally on from terminal 379 unless an
15 abnormal overrange condition exists on shift
approximation register 364. Thus, AND 407 goes
on, inverter 410 goes off, inverter 413 goes on,
and FET 418 goes on to energize solenoid coil 419.
Coil 419 is energized by way of 12 volt supply via
20 line 429, resistor 428, line 427, through coil 419
to line 421, FET 418, line 420, to ground 6.

During operation of the hospital
unit, solenoid coil 438 associated ith solenoid
valve 20 is normally energized to thereby connect
25 the high flow orifice into the pneumatic system.
To accomplish this, the output of AND 439 is on
because line 435 from terminal 1127 is on unless
an abnormal condition exists, line 436 from terminal 379 is energized unless an overrange condition exists on SAR 364, and line 437 i on unless
30 a solenoid abnormality is detected. The on output
from AND 439 is transmitted via line 440 to in-
verter 441 which output is off via line 442 to
inverter 443 and AND 444. The output from in-
35 verter 443 is on which is transmitted via line
444b to current limiting resistor 445 (100K),

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1 terminal 444a, and AND 446a. The other side of
resistor 445 connects to the gate G of field
effect transistor [FET] 446 via line 447.

5 The circuit for energizing solenoid
coil 438 is similar to that for energizing sole-
noid coil 419. The on signal to gate G of FET 446
causes FET 446 to conduct from drain D through to
source S and via line 448 to ground 6. Drain D of
10 FET 446 is connected via line 449 to the anode of
diode 450, to one side of solenoid coil 438, and
to resistor 451 (4.02K) the other side of which is
connected to ground 6 via line 452. When FET 446
is conducting, current flows through line 429 from
15 the 12 V.D.C. source through current limiting
resistor 455 (100 ohms), then through line 456,
coil 438, line 449, FET 446, line 448, to ground
6. Diode 450 is in parallel with coil 438 to
protect the FET 446 from surge currents when coil
20 438 is de-energized. Line 456 also connects to
capacitor 456a the other side of which is
connected to ground 6 via line 456b; capacitor
456a provides a "snap" to quickly energize coil
438. If any of the inputs to AND 439 go off in
25 the event of an abnormal condition, AND 439 goes
off, this by way of inverters 441 and 443 and
resistor 445 turns off FET 446. When FET 446
turns off, solenoid coil 438 is de-energized.

30 The balance of the circuit of Sole-
noid Control and Monitor module 400 is the moni-
toring portion which detects a solenoid coil
status different from nominal.

35 For the sake of an example, assume
that FET 418 has failed so that an open circuit
exists continuously between drain D and source S.
Furthermore, assume that the patient is in the

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1 exhale portion of the breath cycle, which means
that FET 418 is receiving voltage at gate G and
that without the failure FET 418 would be con-
ducting to thereby energize solenoid coil 419.
5 With the open circuit on FET 418, a voltage value
exists at line 421 by virtue of the circuit con-
nection through resistor 423 and through coil 419,
line 427, resistor 428 to the 12 V.D.C. voltage
source.

10 This voltage is transmitted via
line 421 to resistor 457 (1K) and from the other
side of resistor 457 via line 458 to the anode of
diode 459, from the cathode of diode 459 via line
15 460 to inverter 461. Voltage source V_{DD} provides
a proper digital biasing voltage via line 462 and
resistor 463 (100K) to line 460. Thus by virtue
of the open circuit across the drain and source of
FET 418, inverter 461 receives an input voltage.
20 Inverter 461 output is off which output is con-
nected via line 464 to inverter 465 and AND 414.
Because the input to inverter 465 is off, its
output is on via line 466 to AND 411. The other
input to AND 411 is on via 408 because the output
25 of AND 407 is on indicating that the solenoid coil
419 should be energized. Thus AND 411 is on via
line 467 to OR 468. The on output of OR 468 is
transmitted via line 469 to OR 470 whose output is
transmitted via line 471 to inverter 472 and flip-
flop 473. Because the input to inverter 472 is
30 on, its output via line 474 to OR 475 is off. The
other input to OR 475 via line 476 from terminal
828 is normally off unless a reset condition
exists. Thus, the output of OR 475 is off which
35 removes a reset signal from flip-flops 473 and 477
via line 478.

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1 Flip-flops 473 and 477 are conven-
tional "D" flip-flops with reset, each having reset
terminal R, clock input terminal C, data input
5 terminal D, and output terminal Q. Terminal C of
flip-flops 473 and 477 each receive ten hertz up
pulse clock pulses from terminal C12 via line 479.

 Because of the on input at terminal D
of flip-flop 473, terminal Q goes on at the next
10 incoming clock pulse at terminal C. The on output
at terminal Q of flip-flop 473 is transmitted via
line 480 to terminal D. of flip-flop 477. At the
very next clock pulse terminal Q of flip-flop 477
goes on. The use of the two flip-flops 473 and 477
15 in combination with the ten hertz clock pulses
produces a delay of about 200 milliseconds, which is
necessary because of the real time delay in the
operation of solenoids 419 and 438.

 The output from terminal Q of flip-
flop 477 is transmitted via line 481 to terminal S
20 of flip-flop 482 which is a conventional "S" type
flip-flop with set and reset and includes set ter-
minal S, reset terminal R, output terminal Q, and
output terminal \bar{Q} . The on signal at terminal S of
25 flip-flop 482 causes terminal Q to go on and \bar{Q} to go
off.

 When terminal Q of flip-flop 482 goes
on, this output is transmitted via line 483 to
terminal 484a, 484b, 484c, and 484d. The on signal
30 at terminals 484a-d indicates to various circuits
(described in detail below) that an abnormal condi-
tion exists. When terminal \bar{Q} of flip-flop 482 goes
off, the output of AND gates 405 and 439 go off to
de-energize both solenoid coil 419 and 438 through
35 the circuitry described above. Because of the open
circuit failure of FET 418, solenoid coil 419 is
already de-energized.

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1 The operation of the monitor circuit-
ry associated with solenoid coil 438 is very similar
to that associated with solenoid coil 419. For the
5 sake of a second example, assume that FET 446 has
failed with a continuous open circuit between drain
D and source S and that gate G is receiving a vol-
tage signal indicating that solenoid coil 438 should
be energized. The voltage produced across the open
10 circuit of FET 446 and across resistor 451 to ground
6 is transmitted via line 449 to resistor 485 (1K)
and from there via line 486 to the anode of diode
487. From the cathode of diode 487 voltage is
transmitted via line 488 to inverter 489. Digital
15 biasing voltage is supplied from terminal V_{DD} via
line 462 to resistor 490 (100K) and from there to
line 488. Resistor 490 in combination with diode
487 bias the analog voltage to the proper digital
voltage to provide the proper input to inverter 489.

20 Because the input to inverter 489 is
on, its output is off via line 490a to inverter 491
and AND 444. The on output of inverter 491 is
transmitted via line 492 to AND 446a. AND 446a is
on because its other input via line 444 is also on
25 because of the on signal from inverter 443. The on
output of AND 446a is transmitted via line 493 to OR
494. The on output from OR 494 is transmitted via
line 495 to AND 496.

30 The second input to AND 496 is sup-
plied from switch 497 via line 498. Switch 497 is
selectable between a position at terminal 499 which
is clamped to ground 6 or a position 401a which is
clamped to voltage V_{DD} . When switch 497 is switched
to terminal 499 the input to AND 496 by line 498 is
35 off continuously which continuously disables AND
496. The grounded position of switch 497 is select-

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1 ed at the factory when the device is used in the
home application. In this application solenoid 20
is not provided and thus there is no need to monitor
5 the status of a nonexistent solenoid coil. However,
the circuitry is provided as a matter of manufactur-
ing economics. In the hospital application, sole-
noid 20 is provided and there is a need to monitor
the status of the circuit associated with solenoid
10 coil 438. Thus, in this mode, switch 497 is set at
the factory to terminal 401a thus providing a con-
stant on signal via line 498 to AND 496. The switch
is shown in the position for the hospital applica-
tion and thus the on input via line 498 causes AND
15 496 to go on via line 402a to OR 470. The on output
from OR 470 activates flip-flops 482, 477, and 473,
as described above.

Another monitoring function also
exists. If AND 407 is off indicating that solenoid
20 coil 419 should be de-energized but FET 418 is
conducting instead, then a very low voltage exists
at line 421. In this situation AND 414 is on be-
cause it is receiving a signal via line 412 from
inverter 410 and the other input to AND 414 is on
via line 464 from inverter 461. The on output from
25 AND 414 is transmitted via line 403a to OR 468. The
on output of OR 468 activates flip-flops 482, 477,
and 473 as described above.

If a similar abnormality exists
30 associated with solenoid coil 438, then AND 444 is
receiving an on input via line 442 from inverter
441. Additionally, AND 444 is receiving an on input
via line 490 from inverter 489. Thus, AND 444 goes
on which output is transmitted via line 404a to OR
35 494. The on output from OR 494 activates flip-flops
482, 477 and 473 as described above.

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1 In summary, whenever AND 407 is on,
very low voltage should exist at the drain of FET
418. If instead voltage exists at drain D of FET
418 then AND 411 goes on and flip-flop 482 produces
5 an output at Q and turn off \bar{Q} . 1 If AND 407 is off
then the voltage should exist at drain D of FET 418.
If this relationship does not exist then AND 414
goes on to similarly activate flip-flop 482. An
analogous situation exists for solenoid coil 438.
10 If AND 439 is on then, low voltage should exist at
drain D of FET 446. If this relationship does not
exist, and 446 goes on and flip-flop 482 output Q
goes on and \bar{Q} goes off. If AND 439 is off then a
voltage should exist at drain D of FET 446. If this
15 relationship does not exist, the output of AND 444
goes on which causes output Q of flip-flop 482 to go
on and \bar{Q} to go off.

Flip-flops 473, 477, and 482, once
20 activated by data inputs require a reset signal at
terminal R via line 476 from terminal 828 to deacti-
vate the abnormal indication status.

Solenoid Control and Monitor 400 also
includes a visual indication whenever AND 407 is off
to indicate visually that solenoid coil 419 is
25 de-energized and allowing oxygen to flow continu-
ously. This function is provided by light emitting
diode 405a. Whenever the output of OR 409 is off,
current supplied by voltage source V_{DD} flows through
line 406a, current limiting resistor 407a (1K), line
30 408a, diode 405a, and line 409a to the output of OR
409. Light emitting diode 405a is off whenever OR
409 receives an input via line 408 from AND 407 or
when OR 409 receives an input via line 410a from
35 terminal 820.

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1 5. Fig. 5, Three-Breath Timer 500

 The purpose of Three-Breath Timer
module 500 is to determine and transmit count data
corresponding to the total duration of the imme-
diately preceding three breath cycles. Four eight-
bit counters are used for this purpose. At the
beginning of inhalation one of the counters in
sequence is selected or coupled, which selection or
coupling stops that counter from counting input
clock pulses. The other three counters, not select-
ed, that is, decoupled, continue to count input
clock pulses. As each counter is selected or coup-
led in sequence, the count existing on the selected
or coupled counter corresponds to the total count of
the three previous breaths. Thus, by the use of
four counters, one of which is transmitting data at
any one time while the other three are counting
clock pulses, the circuit is able to provide data
corresponding to the duration of the three previous
breaths. Similarly, if the data from one previous
breath were desired, two counters would be required;
if the data from the four previous breaths were
desired, five counters would be required, and so
forth. Data from the three previous breaths is used
in this preferred embodiment as a matter of design
choice to provide data that is very recent but also
representative.

 The operation of Three-Breath Timer
500 begins with reception of an on signal from
terminal 404 of Solenoid Control and Monitor 400
which is transmitted to AND 501 via line 502. AND
501 receives its other input from terminal 711 via
line 503. The off signal at terminal 711 indicates
that blanking 700 has received a flow initiation
signal. The input at terminal 404 indicates that

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1 solenoid control 400 has de-energized solenoid valve
22 to allow oxygen to flow to the patient. The
output from AND 501 is transmitted via line 504 to
5 counter selector or coupler 505 and to output terminal 506. The output from terminal 506 is delivered to the flow initiation section 302 as explained above in connection with that circuit to form the flow initiation signal into a pulse.

10 Counter selector 505 is a conventional eight-bit Johnson counter, here using only the first five bits. Counter selector 505 includes reset terminal R, clock enable terminal CE, clock input terminal C, and bit output terminals Q_0 , Q_1 ,
15 Q_2 , Q_3 , and Q_4 (output terminal for bits Q_5 , Q_6 , Q_7 are not shown because they are not used). Terminal C is clamped on continuously by voltage V_{DD} via line 507. Terminal CE receives input from AND 501 via line 504.

20 For the sake of this illustrative example, assume that terminal Q_3 is on and terminals Q_0 , Q_1 and Q_4 , are off, all just before receiving an input at terminal CE. When AND 501 output goes off to terminal CE of selector 505, Q_3 goes off and Q_4
25 goes on. The output from Q_4 is transmitted via line 505a to NAND 508. NAND 508 receives its other input via line 509 from terminal C5 which is a 100 kilohertz up pulse signal. NAND 508 output then goes off at the very next input clock pulse received on
30 line 509 after terminal Q_4 of selector 505 goes on. When the output from NAND 508 goes off via line 510 to NAND 511, NAND 511 then goes on via line 512 to terminal R of selector 505 to set Q_1 on and Q_1 - Q_4 off. However, the input to terminal CE is off and the input to terminal C is on, which causes terminal
35 Q_0 to go on immediately. When the reset signal was

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1 received at terminal R, Q_4 immediately went off to
remove the reset signal thus allowing Q_0 to go on.
At this point Q_1 , Q_2 , Q_3 , and Q_4 are all off. Also
5 at this point the input to AND 501 via line 503 is
off because the on signal received from terminal 711
goes off when Blanking 700 receives a flow initia-
tion signal. With AND 501 off, selector 505 is
disabled, which thereby holds the output Q_0 on. In
10 the next breath cycle, when another valid inhalation
is sensed the inputs to AND 501 will both go off,
which will advance selector 505 on output from Q_0 to
 Q_1 and so on with each valid inhalation.

In this way, selector 505 sequential-
15 ly turns on outputs Q_0 , Q_1 , Q_2 , and Q_3 and back
again to Q_0 making a rapid transition through Q_4 for
reset purposes only.

The output from terminal Q_0 of se-
lector 505 is transmitted via line 513 to line A_0
20 which line is common to all eight data decoders
521a, 521b, 521c, 521d, 521e, 521f, 521g, and 521h.
The on signal existing on line A_0 enables each
decoder 521a-h to transmit the input signal existing
on the B_0 of each to the Q terminal of each. Simi-
25 larly, if terminal Q_1 of selector 505 were on in-
stead, it is connected via line 514 to line A_1 and
the on status of A_1 would transfer the data on all
the B_1 terminals of data selectors 521a-h to the
output Q of each data decoder. Similarly, terminal
30 Q_2 of counter selector 505 is connected via line 515
to line A_2 , and terminal Q_3 of counter selector 505
is connected via line 516 to line A_3 . If Q_2 of
counter selector 505 is on, line A_2 is on and B_2
input is transferred to terminal Q output of each
35 decoder 521a-h respectively. Similarly, if Q_3 of
counter selector 505 is on, A_3 is on, and the data

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1 on terminal B_3 is transferred to output terminal Q
of each data selector 521a-h. In this example,
terminal B_0 of each data selector 521a-h transfers
5 its incoming data to output terminal Q of each
data sender 521a-h which is transmitted respec-
tively via lines 515a, 515b, 515c, 515d, 515e,
515f, 515g, and 515h respectively to terminals D_0 ,
 D_1 , D_2 , D_3 , D_4 , D_5 , D_6 and D_7 respectively.

10 Counters 516, 517, 518, and 519,
are each composed of two conventional four-bit up
counters conventionally connected to form an
eight-bit counter. Each eight-bit counter 516-519
includes output terminals Q_0 (least significant
15 bit), Q_1 , Q_2 , Q_3 , Q_4 , Q_5 , Q_6 , and Q_7 (most signi-
ficant bit). Each counter also includes pre-set
input terminals for each bit, P_0 (least signifi-
cant bit), P_1 , P_2 , P_3 , P_4 , P_5 , P_6 , and P_7 (most
significant bit). Additionally each counter
20 includes clock input terminal C, binary decimal
selector terminal B/D, count up-down selector
terminal U/D, and preset enable terminal P_E .
Terminals B/D and U/D on each counter are clamped
high via line 520 from voltage source V_{DD} to
select a binary up count.

25 Each bit output terminal Q_{0-7} from
each counter 516-519 is connected individually to
the appropriate input of each decoder 521a-h.
That is, the eight outputs from counter 516 are
connected respectively to the B_0 input terminal of
30 each decoder 521a-h. Specifically regarding
counter 516, Q_0 is connected to B_0 of decoder 521a
by line 522a; Q_1 is connected to B_0 of decoder
521b by line 522b; Q_2 is connected to terminal B_0
of decoder 521c via line 522c; Q_3 is connected to
35 terminal B_0 of decoder 521d via line 522d; Q_4 is

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1 connected to terminal B_0 of decoder 521e via line
522e; Q_5 is connected to terminal B_0 of decoder
521f via line 522f; Q_6 is connected to terminal B_0
5 of decoder 521g via line 522g, Q_7 is connected to
terminal B_0 of decoder 521h via line 522h. Simi-
larly, the outputs of Q_{0-7} of counter 517 are
connected to the B_1 terminals of decoders 521a-h
respectively and the outputs Q_{0-7} of counter 518
10 are connected to the B_2 terminals of decoders
521a-h respectively. The output connections
between counters 517 and 518 and decoders 521a-h
are not shown in Fig. 5 because the multitude of
connecting lines would make the drawing difficult
15 to read. In order to further illustrate, the
connections between counter 519 and the B_3 termi-
nal of decoders 521a-h respectively are shown via
lines 523a, b, d, c, d, e, f, g, h, respectively.

The output Q_0 of counter selector
505 is transmitted via line 513 to line A_0 of
20 decoders 521a-h as discussed above and also to
inverter 524 whose output immediately goes off at
line 525 when Q_0 goes on. When inverter 524 goes
off, and 525 output goes off via line 526 to
terminal C of counter 516. When AND 529 goes off,
25 the 4.16 hertz up pulses received via line 527
from terminal C14 can no longer clock through AND
525 and the up count on counter 516 stops. Be-
cause the output via line 513 to line A_0 of de-
coders 521a-h is on, the output from counter 516
30 transmits on through terminal B_0 of each decoder
to the output Q of each decoder to data output
terminals D_0-D_7 . Thus, when the up count on
counter 516 was stopped, the accumulated count
data transmitted through to terminals D_{0-7} . This
35 up count represents the accumulated count of the

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1 three previous breath cycles. It will be appreciated that this accumulated count inherently represents a measured breath rate.

5 When inverter 524 went off, this output was transmitted via line 525 to flip-flop 528. Flip-flop 528 is a conventional D type with reset and includes data input terminal D, reset terminal R, clock input terminal C, and output terminal \bar{Q} . (Output terminal Q is not shown because it is not used.) Terminal C receives a 10 one kilohertz downpulse signal via line 529 from terminal C8. When inverter 524 output went off, the input data received at terminal D of flip-flop 528 also went off and upon the rising edge of the 15 very next clock input at terminal C, \bar{Q} went on via line 530 to AND 531. AND 531 receives its other input from inverter 524 via line 525. When counter selector 505 advances on the next breath cycle from Q_0 to Q_1 , the input to inverter 524 will go 20 off and its output will go on to AND 531. Because the other input via line 529 is already on, AND 531 output goes on via line 532 to OR 533 which goes on via line 534 to terminal P_E of counter 516. With an on input at terminal P_E , counter 516 25 is enabled to load the preset values existing at P_{0-7} . Terminals $P_0, 2, 3, 4, 6$ and 7 are clamped to ground 6 via line 535. Terminals P_1 and P_5 are connected via line 536 to the output Q terminal of flip-flop 537. At this point in the 30 sequence the output from flip-flop 537 is off and so all of the values at preset terminals P_{0-7} are off and when counter 516 receives the preset enable signal at P_E , it loads all of these zero values into bits Q_{0-7} . In this way, counter 516 35 is reset to zero for all output bits when counter

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1 selector 505 advances from Q_0 to Q_1 . At the same
time, when inverter 524 goes on, AND 525 will be
enabled to begin transmitting clock pulses to
5 terminal C of counter 516. Thus, when counter 516
is de-selected or decoupled by counter selector
505 by virtue of terminal Q_0 of selector 505 going
off, inverter 524 goes on which causes flip-flop
528 to set all counter values to zero, which
10 allows counter 516 to again receive clock pulses
at terminal C.

The operation of counter 517 is
very similar to that of counter 516. When Q_1 of
selector 505 goes on, this output is transmitted
via line 514 to inverter 538 whose output goes off
15 via line 539 to AND 540. When inverter 538 goes
off, AND 540 output goes off via line 541 to
terminal C of counter 517. When the output of
inverter 538 went off the input to terminal D of
flip-flop 541 went off also. Flip-flop 541 is
20 identical to flip-flop 528. Additionally, AND 542
was disabled via line 539 when inverter 538 went
off. When counter selector advances from Q_1 to Q_2
and inverter 538 thus goes back on, AND 542 is
enabled via line 539 and line 543 from the \bar{Q}
25 output of flip-flop 541. The on output from AND
542 is transmitted via line 544 to terminal P_E of
counter 517 which loads zeroes into all eight bits
of counter 517 thus resetting the counter. Addi-
tionally, with inverter 538 output on, AND 540 is
30 enabled to transmit clock signals via line 541 to
terminal C of counter 517. The construction and
operation of counters 518 and 519 are identical to
those described for counter 517.

35 The reset and preset enable func-
tion of counter 516 differs from that of 517-519

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1 only in the addition of OR 533 with counter 516.
This is provided to enable a master reset signal
to be received by OR 533 from terminal 828 via
5 line 545. Line 545 also connects to the input of
inverter 546 whose output is connected via line
547 to NAND 511.

The preset function of counters
516-519 is used to preload values into counters
516-519 whenever flip-flop 537 output is on. This
10 occurs only when terminal 834 is on during condi-
tions to be described below in the description of
Reset and Power Monitor 800 (e.g. solenoid fail-
ure, power up). Flip-flop 537 is a conventional
15 "D" type flip-flop with set function and includes
data input terminal D, set input terminal S, clock
input terminal C, and output terminal Q, which
output is transmitted via line 536 to various
preset terminals (\bar{P}_{0-7}) of counters 516-519. An
on signal at terminal 834 is transmitted via line
20 548 to terminals D and S of flip-flop 537 and to
inverter 549. The on input to inverter 549 causes
its output to go off via line 550 to AND 551. AND
551 then transmits 100 hertz up pulses received
via line 552 from terminal C11. These clock
25 output pulses from AND 551 are transmitted via
line 553 to terminal C of flip-flop 537. The
provision of the clock signals to AND 551 provides
a slight time delay before terminal Q of flip-flop
537 goes on.

30 With line 536 being on, each coun-
ter 516-519 is able to load predetermined counts.
Counter 516 is wired for a preloaded count of
decimal 34 by applying the on signal to bits P_1
and P_5 . Counter 517 is loaded with a count of
35 decimal 28 by providing the on signal to bits P_2 ,

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1 P₃, and P₄. Counter 518 is preloaded with decimal
17 by connecting terminals P₀ and P₄. Counter 519
is preloaded with decimal value 6 by connecting
5 terminals P₁ and P₂. The balance of the preset
terminals are clamped low, i.e. zero, by line 535
to ground 6. It is necessary to preload count
data into counters 516-519 whenever a three breath
history does not exist for the counters. For
10 example, when the unit is first turned on.

6. Fig. 6, Flow Pulse Circuit 600

Flow Pulse Circuit module 600
determines the time duration of the oxygen pulse
supplied to the patient. The circuit does this by
15 selecting a value in a read-only memory which
value is selected based on the pulse count data
received from Three Breath Timer module 500 and
based on binary encoded decimal information re-
ceived from the prescription flow dial mechani-
cally attached to solenoid valve 20. The values
20 stored in the read-only memory are determined so
that the patient receives the substantially physi-
ologically equivalent oxygen from the pulse as the
patient would receive from continuous oxygen flow.
25 That is to say, the preferred values in memory are
based on an assumed I/E ratio of 1 to 1.5 as
discussed above in connection with graph 1305, to
provide a constant "minute volume" of oxygen; this
is a conservative ratio assuring adequate oxygen
30 to the patient under normal conditions. Other
ratios are of course possible (and easily substi-
tutable into memory), as is the expedient of
continuously measuring the I/E ratio.

The operation of Flow Pulse Circuit
35 600 begins with conventional "D" type flip-flop

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1 with reset 601 which includes data input terminal
D, clock input terminal C, reset terminal R, and
output terminal \bar{Q} (terminal Q is not shown because
5 it is not used). Terminal R can receive a reset
input from terminal 834 via line 602 which line is
also connected to inverter 603. Terminal D re-
ceives an input from terminal 404 which is an
output from solenoid control and monitor 400 via
10 line 603. Terminal C receives 100 hertz up pulse
clock signals from terminal C11 via line 604.
Terminal \bar{Q} transmits its output via line 605 to
NAND 606 which receives its other input via line
607 from inverter 603. Terminal 834 is normally
15 off unless a reset condition exists (e.g. solenoid
failure, power up).

In normal operation before the
patient has inhaled, terminal 404 is on and as a
result terminal \bar{Q} of flip-flop 601 is off, which
disables NAND 606 whose output is thus on via line
20 608 to hold counters 609 and 610 in a reset con-
dition.

When the patient inhales, Solenoid
Control and Monitor 400 receives a flow initiation
pulse which causes terminal 404 to go off. When
25 this occurs, the very next clock input pulse at
terminal C of flip-flop 601 causes \bar{Q} to go on.
This delay of one clock pulse between the time
terminal 404 goes off and \bar{Q} goes on gives Three
Breath Timer 500 the amount of time necessary to
30 select the next counter. With terminal \bar{Q} of
flip-flop 601 on via line 605 to NAND 606, the
output from NAND 606 goes off; inverter 603 is on
to satisfy the other input to NAND 606 because no
reset signal is being received at terminal 834.
35 When the output of NAND 606 goes off, up counters

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1 609 and 610 are no longer in reset condition and
are able to begin counting pulses received to up
counter 610 via line 611. At this point Flow
5 Pulse Circuit 600 begins timing the duration of
the oxygen flow pulse.

The timing function of flow pulse
circuit 600 centers about read-only-memory [ROM]
612. ROM 612 is a conventional read-only-memory
structure having 512 locations of eight bits each.
10 Nine address inputs are provided and the output is
provided as eight bits of data. In the drawing,
the address inputs are represented on the leftmost
side of ROM 612 at terminals 0, 1, 2, 3, 4, 5, 6,
15 7, and 8. In the drawing, the output terminals
are on the rightmost side of ROM 612 and labeled
0, 1, 2, 3, 4, 5, 6, and 7 ranging from the least
significant bit to the most significant bit re-
spectively. The memory of ROM 612 is mapped into
20 a plurality of sections only two of which are used
for the hospital and home embodiments respective-
ly. Memory locations 0 through 9 are used for the
hospital mode and 10 through 99 for the home unit
application.

25 Switch 613 is connected to voltage
source V_{DD} (+5 V.D.C.) via line 614 which is the
position (as shown) for home unit application and
switch 613 is clamped to ground 6 via line 616 for
the hospital unit. In the home unit application,
30 switch 613 is positioned as shown to supply a
continuous on voltage via line 615, address inputs
7 and 8 are on, AND gates 618, 619, 620, 621, and
622 are enabled, and the outputs of inverters 623
and 624 are off via lines 625 and 626 respectively
35 to disable AND gates 627 and 628.

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1 In the hospital mode with switch
613 selected to ground, AND gates 618-621 are
disabled which prevents any input to the memory of
ROM 612 from terminals D3, D4, D5, and D6 via
5 lines 629a, 629b, 629c, 629d respectively. The
data input from terminals D3-D6 are not needed in
the hospital unit application because the oxygen
pulse wave form is a regular square wave pulse
10 (See Fig. 13, graph 1305) and as such, is more
predictable in its physiological effect on the
patient's partial pressure of arterial oxygen.
Thus, not as many empirically derived values need
be stored in ROM 612 and for this reason the
15 address input in the hospital unit comes only from
the flow selector dial which provides the binary
encoded demical output [BCD] 630. With switch 613
thus selected to the hospital unit, address inputs
at terminals 4-8 are always off and inputs at
terminals 0-3 of the address input are needed.

20 BCD 630, to address the hospital
memory section, basically comprises four switches
631a, 631b, 631c, and 631d which range from the
least significant bit to the most significant bit
respectively. One side of each switch 631a-d is
25 connected via line 632 to voltage source V_{DD} . The
other side of switches 631a-c are connected via
lines 632, 633, and 634 to address terminals 0, 1,
and 2 respectively. The output from switch 631d
is transmitted via line 635 to AND 627 whose
30 output is transmitted via line 636, OR 638, and
line 639 to terminal 3.

 The four switches can convey a
total count of decimal 15 when all switches are
closed as shown. However, in the home unit the
35 maximum allowable prescription flow rate is seven

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1 liters per minute; when switch 613 is selected to
the home unit, the input to inverter 623 is on and
its off output disables AND 627 thus preventing
5 any data flow to the address from switch 631d
which in turn represents the most significant bit
which represents a count of decimal 8 when switch
631d is closed. Thus, in the home mode address,
terminal 3 receives input terminal D₃ via line AND
621, 621a via line 640, OR 638, and line 639.

10 In the hospital mode however, a
continuous flow rate greater than seven is select-
able and the bit data from all four switches is
needed. In this mode AND 627 is enabled because
inverter 623 is on and AND 627 thereby transmits a
15 bit count from switch 631d.

The outputs from switches 631a-d at
lines 632-635 are tied to V_{SS} (which is D.C.
ground) through resistors 641a, 641b, 641c, and
641d respectively via line 642. This is neces-
20 ssary because of the nature of the CMOS (compli-
mentary metal oxide semiconductor) devices used in
this circuit in order to prevent line voltage from
drifting when any of switches 631a-d open.

25 In the home embodiment, a more
complicated oxygen flow pulse shape is encountered
because of the pneumatic structure of the device
(see Fig. 13 graph 1305). Because of this fact, a
greater number of values are needed to be stored
in the memory of ROM 612 and address data is
30 needed at address terminal 3-8 in addition to that
provided by BCD 630 at address terminal 0-2. In
the home mode as described above, address termi-
nals 7 and 8 are on, AND gates 618-621 are enabled
and the output of inverter 623 is off to thereby
35 disable AND 627 to prevent address data from BCD

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1 switch 631d. With AND gates 618-621 enabled ROM
612 can received address data at terminals 3-6
from input data terminals D3, D4, D5, D6, which
represent count data from Three Breath Circuit
5 500. The data input from D3-D6 only is used
because the additional resolution that would be
provided by the use of data from terminals D0, D1,
D7 is not needed for the purposes of ROM 612
address.

10 As described above, input data from
terminal D3 is transmitted to address terminal 3.
Address data from terminal D4 is received at
address terminal 4 via line 629b, AND 620, and
line 643. Address data from terminal D5 is re-
15 ceived at address terminals 5 via line 629c, AND
619, and line 644. Input data from terminal D6 is
transmitted to address terminal 6 via line 629d,
AND 618, and line 645.

20 The data from BCD 630 is also
transmitted to NOR 646 via lines 632-635. If the
continuous flow dial is slected to zero liters per
minute all four inputs to NOR 646 are off and NOR
646 goes on via line 647 to AND 628. If the
hospital mode is selected at switch 613, the input
25 to inverter 624 is off whose output is on to AND
628. With both inputs on, AND 628 output goes on
via line 648 to Schmitt-trigger OR 649 whose on
output is transmitted via line 650 to output
terminal 651 which, through circuitry described in
30 more detail below, resets the system to provide
continuous oxygen flow. That is, in the hospital
mode, if a continuous flow of zero is selected the
entire system is disabled from supplying oxygen
pulses.
35

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1 In the home mode, the same continuous
ous flow rate selector dial is provided but with
an additional mechanical stop which inhibits a
continuous flow rate selection greater than seven.
5 However, if the dial would be mechanically forced
beyond the seven liter per minute position, line
635 would be on to AND 622. The other input to
AND 622 is also on and the output of AND goes on
via line 652, OR 649, line 650, to terminal 651.
10 Thus a forced selection above seven liters per
minute on the home embodiment indicates a malfunction
which resets the system and puts it into a
continuous oxygen flow mode.

15 The next part of flow pulse circuit
600 takes an incoming clock pulse and scales the
frequency to an output determined by the data of
ROM 612.

20 Conventional "D" flip-flop with
reset 653 includes input data terminal D, clock
terminal C, reset terminal R, and output terminals
Q and \bar{Q} . Terminal R can receive a reset signal
from terminal 838 via line 654 which is off unless
a reset condition or flow initiation pulse exists.
25 Terminal C receives a ten kilohertz downpulse
clock signal from terminal C6 via line 655.
Terminal D receives input from terminal \bar{Q} via line
656. With this arrangement flip-flop 653 scales
the incoming ten kilohertz downpulse signal to a
five kilohertz square wave signal with a 50% duty
30 cycle at terminal Q. This occurs because an input
of one on terminal D causes \bar{Q} to go off at the
very next incoming clock pulse which changes the
input to terminal D to 0 which causes \bar{Q} to then go
on at the very next incoming clock pulse. In this
35 way the outputs of both \bar{Q} and Q are five kilohertz
signals.

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1 The five kilohertz output from
terminal \bar{Q} of flip-flop 653 is also transmitted
via line 656 to the clock input terminals of
conventional four-bit downcounters 657 and 658.
5 Counters 657 and 658 are identical four-bit down-
counters connected to one another to effectively
form an eight-bit downcounter. Each counter 657
and 658 includes input data preset terminals P_0 ,
 P_1 , P_2 , and P_3 . Additionally, each counter in-
10 cludes carry in terminal CI, carry out terminal
CO, present enable terminal PE, clock input termi-
nal C, binary decimal selector terminal B/D, and
up or downcount selector terminal U/D. Both U/D
terminals are clamped low to terminal V_{SS} via line
15 659 so that each downcounts. The B/D terminal of
each counter is clamped high to V_{DD} via line 660
to select the binary count mode. Additionally,
terminal CI of counter 658 is clamped low via line
659 to voltage terminal V_{SS} . Counter 658 receives
20 input data at terminals P_{0-3} via lines 661a, 661b,
661c, 661d respectively from ROM 612 output termi-
nals 0-3 respectively. Counter 657 receives input
data at terminals P_{0-3} via lines 661e, 661f, 661g,
661h respectively from ROM 612 output terminals
25 4-7 respectively. Counter 657 and 658 each re-
ceive inputs at terminals PE via line 662 from
flip-flop 663.

30 Flip-flop 663 is identical to
flip-flop 653 except that terminal Q is not shown
because it is not used.

35 A flow initiation pulse sets ter-
minal 838 momentarily which is transmitted to
terminal R of both flip-flops 653 and 663 via line
654 which initially sets the \bar{Q} output of both
flip-flops 653 and 663 on. When the reset pulse

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1 is removed, and \bar{Q} of flip-flop 663 goes on, coun-
ters 657 and 658 are enabled via line 662 to load
data from ROM 612. As soon as data is loaded,
5 each CO terminal of counters 657 and 658 go on via
lines 667 and 668 respectively to OR 665. OR 665
output is on until all of the bits of counters 657
and 658 are off. The on output of OR 665 is
transmitted via line 611 to terminal D of flip-
10 flop 663. Upon the next clock pulse input at
terminal C via line 664, \bar{Q} goes off which disables
counters 657 and 658 from loading data from ROM
612. At this point counters 657 and 658 can begin
downcounting with each input pulse received at
their respective C terminals via line 656.

15 When the count on both counters 657
and 658 reaches zero, both outputs at CO via lines
667 and 668 go off and OR 665 goes off. When OR
665 output goes off, flip-flop 663 terminal \bar{Q}
output goes on at the next incoming clock pulse at
20 terminal C. When terminal \bar{Q} goes on, counters 657
and 658 are again enabled to load data from ROM
612. As soon as the data is loaded OR 665 goes on
again, \bar{Q} of flip-flop 663 goes off which removes
the enabling input to both counters 657 and 658,
25 and each counter again begins its countdown. The
net effect of the repeated data loading and count-
down of counters 657 and 658 is an output from OR
665 which is a downpulse of frequency equal to
five kilohertz divided by the sum of the ROM data
30 number plus one. Thus the incoming ten kilohertz
input clock signal is scaled according to the
selected ROM data which was selected by the ad-
dress provided by BCD 630 and data from three
breath timer 500 (when the home use is selected).
35

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1 The last portion of Flow Pulse
Circuit 600 uses the downpulse output of OR 665 as
the frequency with which to count the data pro-
vided by three breath time 500.

5 The output of OR 665 is transmitted
via line 611 to upcounter 610 and comparator logic
circuit 669. Upcounter 610 is a conventional
four-bit counter with reset and includes reset
10 terminal R, clock terminal C, enable terminal EN,
and output bit terminals Q₀ (least significant
bit), Q₁, Q₂, and Q₃. Terminal C is clamped to
ground 6 via line 670. When the reset signal from
NAND 606 is removed from terminal R of upcounter
15 610, counter 610 begins counting the rising edge
of the incoming downpulses from OR 665. The
outputs from terminals Q₀₋₃ are transmitted via
lines 671a, 671b, 671c, and 671d respectively to
NAND 672. When all outputs Q₀₋₃ of counter 610
20 are on, NAND 672 output goes off via line 673 to
upcounter 609.

 Upcounter 609 is identical to
counter 610 but with terminal EN clamped high via
line 674 to V_{DD} and terminal C connected via line
673 to the output of NAND 672. This arrangement
25 combines upcounters 609 and 610 into a functional
eight-bit counter with counter 609 receiving the
overflow count from upcounter 610. That is, when
NAND 672 goes off which occurs when a full count
exists on counter 610, the very next input pulse
30 to counter 610 causes all of its bits to go off,
which causes NAND 672 to go on which provides one
count of input to counter 609. In this way coun-
ter 609 receives one bit of input each time coun-
ter 610 overflows. The reset signal to terminal R
35 of counter 609 was removed via line 608 at the

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1 same time it was removed from counter 610. The
output from counter 609 at terminals Q_0 (least
significant bit), Q_1 , Q_2 , and Q_3 (most significant
5 bit) is transmitted via lines 675a, 675b, 675c,
and 675d respectively to comparator logic circuit
676.

Circuits 669 and 676 are conven-
tional count comparator logic circuits. Each
circuit 669 and 676 includes input terminals B_0 ,
10 B_1 , B_2 , and B_3 and input terminals A_0 , A_1 , A_2 , and
 A_3 . Circuit 669 receives input data at terminals
 B_{0-3} from upcounter 610 via lines 671a-d respec-
tively. Logic circuit 669 receives input data
15 from terminals D_0 , D_1 , D_2 , and D_3 of three breath
timer 500 via lines 677a, 677b, 677c, and 677d
respectively to terminals A_{0-3} respectively.
Similarly logic circuit 676 receives inputs at
terminals B_{0-3} from upcounter 609 via lines 675a-d
respectively. Additionally, logic circuit 676
20 receives input at terminals A_{0-3} from terminals
 D_4 , D_5 , D_6 , and D_7 of three breath timer 500 via
lines 678a, 678b, 678c, and 678d respectively.

In logic circuit 669, the terminals
 $A = B$ IN and $A > B$ IN are clamped high via line
25 669 to V_{DD} . The $B > A$ OUT terminal of logic
circuit 669 is connected via line 680 to the $B >$
IN terminal of logic circuit 676. The $B = A$ OUT
terminal of logic circuit 669 is coupled via line
681 to the $B = A$ IN terminal of logic circuit 676.
30 the $A > B$ IN terminal of circuit 676 is clamped
high via line 674 to V_{DD} .

When the functional eight-bit count
represented on the outputs of upcounters 609, 610
exceeds the count delivered by three breath timer
35 terminals D_0 - D_7 to logic circuits 676 and 669,

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1 then B > A OUT of logic circuit 676 goes on which
output is transmitted via line 682 to AND 683, and
output terminals 684 and 685. AND 683 receives
5 its other input as a ten kilohertz up pulse from
terminal C7 via line 686. On the very next clock
pulse received by AND 683 after line 682 goes on,
AND 683 goes on to terminal 687 via line 688.

The output from terminal 684 goes
to Flow Initiation and Rezeroing 300 to start the
10 conversion process of successive approximation
register 364. The output at terminal 687 goes to
Solenoid Control and Monitor 400 to reset flip-
flop 402.

15 7. Fig 7, Blanking 700

When Flow Pulse Circuit 600 times
out the duration of the oxygen pulse and flow
initiation and rezeroing 300 completes the conver-
sion on successive approximation register 364,
20 solenoid valve 22 is energized to end the oxygen
flow to the patient. However, the oxygen pulse
ends while the patient is still inhaling and as a
result inhalation sensor 100 begins indicating
that patient inhalation is occurring. The main
25 purpose of Blanking module 700 is to prevent
inhalation sensor 100 from triggering another
oxygen pulse during the same period of inhalation.
Blanking 700 accomplishes this by preventing Three
Breath Timer 500 from being triggered by AND 501.

30 Blanking 700 receives the output
from Flow Initiation and Rezeroing 300 indicating
that a valid inhalation has occurred at terminal
347 which on signal is transmitted via line 701 to
flip-flop 702 and inverter 703. When inverter 703
35 receives this on signal its output goes off via

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1 line 704 to AND 705. AND 705 then goes off via
line 706 to OR 707. The other input to OR 707 is
from terminal 834 via line 708 which is normally
off unless a reset condition exists. When the
5 output of AND 705 goes off the output from OR 707
goes off via line 709 to remove the reset input to
flip-flop 702.

Flip-flop 702 is a conventional "S"
flip-flop with set and reset and includes input
10 set terminal S, reset terminal R, and output
terminal \bar{Q} (output terminal Q is not shown because
it is not used).

With the reset signal at terminal R
removed and an on signal received at terminals S,
15 \bar{Q} of flip-flop 702 goes off which is transmitted
via line 710 to terminal 711 and flip-flop 712.
The off output at terminal 711 prevents AND gate
501 (Fig. 5) from going on at least as long as the
output from flip-flop 702 is off.

20 Flip-flop 712 is a conventional "D"
type flip-flop with a set function and includes
data input terminal D, clock input terminal C, set
input terminal S, and output terminal Q. Flip-
flop 712 can receive a set signal from terminal
25 834 via line 708 at terminal S which input is
normally off. Flip-flop 712 also receives a one
kilohertz downpulse clock signal from terminal C8
via line 713. Upon reception of the very next
clock pulse at terminal C, the off signal at
30 terminal D (from \bar{Q} of flip-flop 702) clocks
through and turns off terminal Q of flip-flop 712.

When terminal Q of flip-flop 712a
goes off via line 714, downcounters 714 and 715
begin downcounting against the count received from
35 Three Breath Timer 500. The clock pulse delay of

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1 flip-flop 712 in turning off terminal Q output
gives Three Breath Timer 500 time to advance to
the next counter and allows downcounters 714 and
5 715 time to load in the data from the new counter
selected by Three Breath 500, all this occurring
before the output from terminal Q goes off.

Counters 714 and 715 are conven-
tional four-bit counters connected to function as
an eight-bit counter. Each counter 714 and 715
10 includes binary decimal selector terminal B/D,
clock input terminal C, carry in terminal CI,
up/down count selector terminal U/D, preset enable
terminal PE, carry out terminal CO, and data input
terminals P_0 (least significant bit), P_1 , P_2 , and
15 P_3 . Each B/D terminal is clamped high to voltage
source V_{DD} via line 716 to thereby select the
binary count mode. Each U/D terminal is clamped
to ground 6 via lines 717 and 718 respectively to
select the downcount mode. Additionally, each
20 counter 714, 715 receives twenty hertz up pulse
clock signals from terminal C13 via line 719.
Terminals P_{0-3} of counter 715 receive input data
from terminals D0, D1, D2, and D3 from Three
Breath Timer 500 via lines 719, 720, 721, and 722
25 respectively. Terminals P_{0-3} of counter 714
receive input data from terminals D4, D5, D6, D7
of Three Breath Timer 500 via lines 723, 724, 725,
and 726 respectively. Terminal CI of counter 715
is clamped to ground 6 via line 718.

30 When counter 715 completes the
downcount of the data loaded at terminals P_{0-3} ,
terminal CO, which is on whenever any bit is on,
goes off which output is transmitted via line 727
to NOR 728 and CI of counter 714. When the input
35 to counter 714 at CI goes off, counter 714 then

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1 begins downcounting the data loaded at terminals
P₀₋₃. When the downcount is complete and all bits
are off, terminal CO goes off via line 729 to NOR
5 728. With both inputs off, the output from NOR
728 goes on via line 730 to AND 705. The other
input to AND 705 is on because the input to in-
verter 703 was on only during the short duration
flow initiation pulse received at terminal 347.
10 The output from AND 705 thus goes on through OR
707 to terminal R of flip-flop 702 which resets
flip-flop 702 so that terminal \bar{Q} goes on. When
terminal \bar{Q} goes on, AND 501 of Three Breath Timer
500 is enabled for another cycle. The on output
15 at terminal \bar{Q} of 702 is input to terminal D of
flip-flop 712 and after one clock pulse terminal Q
of flip-flop 712 goes on to the PE terminals of
counters 714 and 715 which enables counters 714
and 715 to reload data existing on terminals D₀₋₇
20 and both counters 714 and 715 are thus ready for
the next cycle as are flip-flops 702 and 712.

Counters 714 and 715 downcount the data
received from Three Breath Timer 500 at a faster
rate (20 HZ) than which that count data was gener-
ated (4.16 HZ). That is, the data is counted down
25 at the rate of 20 hertz but was generated at the
rate of 4.16 hertz. However, the count data
generated by Three Breath Timer 500 covered three
breath cycles where the countdown of blanking 700
takes less than one cycle. Thus, the countdown of
30 blanking 700 is scaled to extend the blanking time
into the exhale portion of the same breath cycle in
which the blanking time started (see Fig. 13).

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8. Fig. 8, Reset and Power Monitor 800

The purpose of Reset and Power Monitor module 800 is to reset the memory elements of the various circuits such as flip-flop counters and registers, to initialize the system, and various components reset if an abnormality occurs.

The power monitor portion of Reset and Power Monitor 800 monitors the 12 V.D.C. power supply for any dip in voltage. That is, this portion activates if the 12 volt power supply drops below approximately 10.7 volts. Power supply voltage at 12 V.D.C. is supplied through a voltage divider to a conventional differential operational amplifier 801 including a positive input terminal, a negative input terminal and an output. Operating voltage for amplifier 801 is supplied from V_{EE} (+8 V.D.C.) via line 802 and is referenced to ground 6 via line 803. Nominal 12 volt D.C. power is supplied via line 804, resistor 805 (290K), and line 806 to the positive input terminal of amplifier 801. The balance of the 12 V.D.C. voltage divider network is formed by line 806 to resistor 807 (100K) the other side of which is connected to ground 6 by line 803. The input to negative input terminal of amplifier 801 comes from line 808 which is part of voltage divider network starting with terminal V_{DD} (+5 V.D.C.), line 809, resistor 810 (100K), line 808, resistor 811 (100K), and line 803 to ground 6.

When the voltage supplied to the positive input terminal of amplifier 801 is greater than that supplied to the negative input terminal, the output of amplifier 801 is on. If the 12 V.D.C. supply voltage drops, the voltage supplied by V_{DD} should still remain steady because

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1 this voltage at +5 V.D.C. is less than the supply
voltage of 12 V.D.C. When the supply voltage
drops to approximately 10.0 volts, the voltage at
the negative input terminal of amplifier 801 is
5 greater than the voltage at the positive input
terminal and amplifier 801 output goes off via line
812 to resistor 815 (4.02K), and then via line 816
to inverter 817 and capacitor 818. Resistor 815
properly biases the output of amplifier 810 for
10 digital operation. The other side of capacitor
818 is connected to ground 6 via line 803.

In normal operation, amplifier 801
output is on with the result that the output of
inverter 817 is off. If the 12 V.D.C. power
15 supply voltage drops, amplifier 801 goes off and
the output from inverter 817 goes on.

Capacitor 818 is used at power up
to delay the on input to inverter 817 to allow the
system to reset to initial values. When amplifier
20 801 initially goes on, current flow into capacitor
818 delays the rise of the input voltage to in-
verter 817 and provides about a one second delay.

The output from inverter 817 is
transmitted via line 819 to terminal 820 which
25 connects with Failure Indicator 900 explained in
more detail below, and with OR 821. OR 821 re-
ceives its other input from terminal 651 via line
822. An on input at terminal 651 indicates that
the selector dial for solenoid valve 20 is set at
30 a flow rate of zero for the hospital unit which is
indicated on BCD 630 (or a flow setting over seven
for the home unit) as explained in connection with
Flow Pulse Circuit 600.

The output from OR 921 is transmit-
35 ted via line 823 to terminal 825 which initiates a

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1 conversion cycle for successive approximation
register 364 and to Schmitt-trigger OR gate 826.
OR 826 receives its other input via line 827 to
5 terminal 222 which is on in the event of an abnormality in oscillator 201.

The output from OR 826 is transmitted via line 827 to terminal 828, and OR gates 829 and 830. The output from terminal 828 is conveyed to the various individual circuits as
10 described in connection with each circuit and functions as a master reset to put virtually all of the memory elements in an initial status.

OR 829 also receives inputs from terminal 484b via line 831 which is on in the
15 event of a solenoid coil abnormality as detected by Solenoid Control and Monitor 400, and terminal 1127 via line 832 which is on in the event Seek/Deliver 1100 is activated which is explained in more detail below. The output from OR 829 is
20 conveyed via line 833 to terminal 834 and OR 835.

OR 835 receives its other input from flow initiation 302, terminal 347 via line 836 which comes on when a valid inhalation is detected. The output from OR 835 is transmitted
25 via line 837 to terminal 838. The second input to OR 830 is also from terminal 346 of flow initiation 302 which is on when a valid inhalation is detected.

30 9. Fig. 9, Failure Indicator 900

The purpose of failure indicator 900 is to provide a visual signal in the event of a system failure or reset. NOR gate 901 receives
35 inputs from terminal 376 of rezero 301 via line 902 which is on in the event an overrange exists

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1 on successive approximation register 364; from
terminal 828 of Reset and Power Monitor 800 which
is on in the event of clock failure, zero oxygen
flow selection, power failure or briefly on power
5 up; from terminal 1161 of Seek/Deliver 1100 via
line 904 which is on whenever Seek/Deliver 1100 is
activated; and from terminal 484c of Solenoid
Control and Monitor 400 which is on whenever a
solenoid abnormality is detected. If any of the
10 inputs to NOR 901 are on, NOR 901 output is off
via line 906 to OR 907.

The other input to OR 907 is from
terminal 820 of Reset and Power Monitor 800 via
line 908 which is on in the event of low power
15 supply voltage or briefly on power up. If both
inputs to OR 907 are off which occurs in the event
of any of the abnormalities described above, then
the off output from OR 907 allows light emitting
diode 909 to go on. The cathode of diode 909 is
20 connected to the output of OR 907 via line 910.
Power is supplied to diode 909 from voltage source
 V_{DD} via line 911, resistor 912 (1K), and line 913
connected to the anode of diode 909.

25 10. Fig. 10, Audible Alarm 1000

Conventional audible alarm 1001 is
activated by an output from OR 1002 via line 1003.
OR 1002 is on if any of its four inputs are on
which indicates an abnormal condition. OR 1002
30 rceives input from terminal 376 of rezeroing 301
via line 1004 which indicates an overrange condi-
tion on successive approximation register 364.
The second input to OR 1002 is from terminal 484d
of Solenoid Control and Monitor 400 via line 1005
35 which indicates an abnormal solenoid control

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1 condition. The third input to OR 1002 is from
terminal 828 of Reset and Power Monitor 800 via
line 1006 which indicates clock failure, zero
5 oxygen flow selection, low voltage power supply,
and briefly on power up. The fourth input to OR
1002 is from flip-flop 1007 via line 1008. An
output from flip-flop 1007 indicates that Seek/
Deliver 1100 has not detected a valid inhalation
for 97.5 seconds.

10 Flip-Flop 1007 is a conventional "D"
type flip-flop with reset and includes data input
terminal D, clock input terminal C, reset terminal
R, and output terminals Q and \bar{Q} . Flip-flop 1007
is reset at terminal R via line 1009 from terminal
15 840 of Reset and Power Monitor 800 which terminal
goes on when a flow initiation pulse occurs or
upon reset conditions described under Reset and
Power Monitor 800. Flip-flop 1007 receives 10
kilohertz up pulses from terminal C7 via line
20 1010.

During the normal reset condition
of flip-flop 1007, \bar{Q} is on via line 1011 to AND
1012. The other input to AND 1012 is from termi-
nal S of Seek/Deliver 1100 via line 1013 which
25 goes on if Seek/Deliver 1100 has not detected a
flow initiation pulse for 7.5 seconds, the details
of which will be described in connection with
Seek/Deliver 1100 below. If this abnormal condi-
tion occurs AND 1012 goes on via line 1014 to
30 flip-flop 1015.

Flip-flop 1015 is a conventional
"S" type flip-flop with set function and includes
input set terminal S, reset terminal R, and output
terminals Q (terminal \bar{Q} is not shown because it is
35 not used). When terminal S of flip-flop 1015

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1 receives an on signal from AND 1012, terminal Q goes on via line 1016 to serial register 1017.

5 Counter 1017 is a conventional eight-bit Johnson counter with input clock terminal C, count enable terminal CE which is clamped to ground 6 via line 1018 which continuously enables register 1017, and output terminal Q₇ which represents the eighth bit (terminals for bits Q₀-Q₆ are not shown because they are not used), and reset terminal R which receives a reset signal from terminal 840 via line 1009 whenever a flow initiation pulse occurs or under the other reset conditions described under Reset and Power Monitor 800.

15 Upon receiving the first input on signal at terminal C from flip-flop 1015, bit Q₀ (not shown) of counter 1017 goes off and bit Q₁ goes on, and so forth with each input signal at terminal C to terminal Q₇ if no reset signal is received in the interim, that is, if no valid inhalation has been detected to cause a reset at terminal R.

25 The on/off input signals at terminal C of counter 1017 are generated by flip-flop 1015. After Seek/Deliver 1100 has delivered continuous oxygen for 7.5 seconds, terminal 1128a of Seek/Deliver 1100 comes on via line 1019 to terminal R of flip-flop 1015 to reset flip-flop 1015. This causes terminal Q to go off. At this time, Seek/Deliver 1100 is waiting for 7.5 seconds for a valid inhalation to occur. If none occurs at the end of this time, terminal 1123 again goes on, AND 1012 goes on, and terminal Q of flip-flop 1015 again goes on to advance serial register 1017 to bit 2. Thus, one cycle of Seek/Deliver 1100

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1 advanced one bit to the next register 1017 takes
15 seconds. If this cycle continues for a total
of 97.5 seconds, bit Q_7 goes on via line 1020 to
5 terminal D of flip-flop 1007 which turns on terminal \bar{Q} and turns on terminal Q of flip-flop 1007.
When terminal Q of flip-flop 1007 goes on audible
alarm 1001 is sounded.

The 97.5 second lapse in detection
of the valid inhalation signal is most likely to
10 occur if the patient removes the cannula. The
audible alarm sounds as a reminder to turn off the
unit and the oxygen flow in order to avoid oxygen
waste. This feature can also be used to sound an
alarm in the event of patient breathing failure or
15 apneic condition.

11. Figure 11, Seek/Deliver 1100

Seek/Deliver module 1100 monitors
patient breath rate and if that breath rate is
20 outside predetermined norms, causes oxygen to be
delivered continuously for 7.5 seconds at the end
of which time, solenoid 22 is re-energized for 7.5
seconds during which time Seek/Deliver 1100 waits
to detect a valid inhalation. If a valid inhalation
25 does not occur during this "seek" time,
solenoid valve 22 is again de-energized to "deliver"
oxygen again for 7.5 seconds. This cycle
continues indefinitely. A breath rate below 8 per
minute corresponds to a 7.5 second gap between
30 valid inhalation pulses and is detected by use of
pulse count timers. Patient breath rate above 53
per minute is detected by use of the count data of
Three Breath Timer 500. Additionally, Seek/
Deliver 1100 provides a 20 second delay on power
35 up before allowing solenoid valve 22 to be ener-

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1 gized to allow the circuitry to warm up and stabilize.

5 "Seek" timing is provided by pulse counters 1101 and 1102. Counters 1101 and 1102 are conventional four-bit binary counters identical to counters 230, 234, 239, 247 and 254 of clock 203. Each counter includes enable terminals EN which are enabled continuously by clamping them high via line 1103 to voltage source V_{DD} , clock terminals C, and reset terminals R. Counter 1101 includes output terminals Q_0 (least significant bit), Q_1 , Q_2 and Q_3 . Counter 1102 includes output terminals Q_0 (least significant bit), Q_1 and Q_2 . Terminal C of counter 1101 receives 10 hertz down pulses from terminal C15 via line 1104.

15 During normal operation, counters 1101 and 1102 receive a reset signal terminal R when a flow initiation pulse occurs at terminal 840 which is transmitted to counters 1101 and 1102 via line 1105, OR 1106 and line 1107. After the flow initiation pulse, counter 1101 begins counting 10 hertz input signals at terminal C. When counter 1101 reaches a count of 9, terminals Q_0 and Q_3 go on via lines 1108 and 1109 respective to NAND 1110 which then goes off via line 1111 to terminal C of counter 1102. At the very next count on counter 1101 (10th input clock pulse), all bits are reset to zero, NAND 1110 goes on and Q_0 of counter 1102 goes on which corresponds to a time duration of one second (10 pulses at 10 hertz on counter 1101). In this way, counters 1101, 1102 are effectively combined. After 7.5 seconds, bits Q_0 and Q_2 of counter 1102 are on and bits Q_1 and Q_3 are off which together represent .5 seconds, and bits Q_0 , Q_1 and Q_2 of counter 1102 are

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1 on corresponding to 7 seconds. The outputs from
terminals Q_0 - Q_2 of counter 1101 are transmitted
via lines 1112, 1113 and 1114 respectively to AND
1115. The on signals from terminals Q_0 and Q_2 of
5 counter 1101 are transmitted via lines 1108 and
1116 respectively to AND 1115. The off status of
 Q_1 of counter 1101 is conveyed via line 1118 to
inverter 1119 which goes on via line 1120 to AND
1115. Thus, at 7.5 seconds without a reset signal
10 on counters 1101 and 102, AND 1115 goes on which
output is transmitted via line 1121 to OR 1122 and
terminal 1123, which terminal output goes to the
97.5 second timer of audible alarm 1000.

When OR 1122 goes on, its output is
15 transmitted via line 1124 to flip-flop 1125.
Flip-flop 1125 is a conventional "S" flip-flop
with set and reset and includes input set terminal
S, reset terminal R, and output terminals Q and \bar{Q} .
When the input to terminal S goes on, terminal Q
20 goes on and \bar{Q} goes off. The off output from
terminal \bar{Q} is transmitted via line 1126 to output
terminal 1127 which off output causes Solenoid
Control and Monitor 400 to de-energize solenoid
valves 20 and 22 which then causes the system to
25 "deliver" oxygen to the patient.

The off status via line 1126 of terminal
Q of flip-flop 25 is also transmitted to OR 1128.
At this point in the cycle, the other three inputs
to OR are normally off. OR 1128 receives an input
30 via line 1129 from terminal 484a which is normally
off unless Solenoid Control and Monitor 400 de-
tects a solenoid coil abnormality. Input to OR
1128 via line 1130 from terminal 828 of Reset and
Power Monitor 800 is normally off unless a reset
35 condition exists. Input to OR 1128 via line 1131

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1 from flip-flop 1132 is off at this point in the
Seek/Deliver cycle. Thus, when flip-flop 1125
output at terminal \bar{Q} goes off, the output from OR
1128 goes off via line 1132a to remove the reset
5 signals from deliver counters 1133 and 1134.

Counters 1133 and 1134 are identical to counters 1101 and 1102 and are interconnected in the same way to time out a 7.5 second delay duration (in addition, counter 1134 uses
10 terminal Q_3 in combination with NAND 1135 and warm-up counter 1136 for the warm-up cycle which will be explained in more detail below). Counter 1133 receives 10 hertz clock input pulses via line 1104 from terminal C15 at terminal C. Both counters are continuously enabled by clamping them to
15 voltage V_{DD} via line 1137. Both receive the reset input from OR 1128 via line 1132 at terminal R. The output from terminals Q_0 and Q_2 of counter 1133 are conveyed via lines 1138, 1139 respectively to AND 1140. The output from terminal Q_1
20 of counter 1133 is transmitted via line 1141 to inverter 1142 which output is transmitted via line 1143 to AND 1140. NAND 1144 receives its inputs from terminals Q_0 and Q_3 of counter 1133 via lines 1138 and 1145 respectively. The output of NAND is transmitted via line 1146 to terminal C of counter 1134. The output from terminals Q_0 , Q_1 and Q_2 of
25 counter 1134 are transmitted via lines 1147, 1148 and 1149 respectively to AND 1140. The input to AND 1140 via line 1150 from NOR 1151 is normally on except during the warm-up time.

When the output from OR 1128 goes
off and removes the reset from counters 1133 and
1134, AND 1140 goes on after 7.5 seconds which
35 output is transmitted via line 1152 to AND 1153.

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1 The other input to AND 1153 is a
continuously on output via line 1154 from terminal
2 \bar{Q} of flip-flop 1155 which output comes on after
the initial warm-up period and stays on thereafter
5 to continuously enabling AND 1153. The output
from AND 1153 is transmitted via line 1156 to OR
1157. The other output to OR 1157 is off after
the initial warm-up period. The output from OR
10 1157 is transmitted via line 1158 to terminal
1158a and to flip-flop 1132, which is a conven-
tional "D" flip-flop including input data terminal
D, clock terminal C, reset terminal R and output
terminal Q (terminal \bar{Q} is not shown because it is
not used). Terminal R receives a reset input from
15 terminal 828 via line 1130 which is normally off
except during a reset condition. Terminal C
receives 10 kilohertz up clock pulses from termi-
nal C7 via line 1159.

20 When the input to terminal D of
flip-flop 1132 receives the on input signal from
OR 1157, the very next clock pulse received at
terminal C turns on terminal Q which output is
transmitted via line 1131 to reset flip-flop 1125
and to reset counters 1133 and 1134 via OR 1128.
25 When counters 1133 and 1134 are reset, AND 1140
goes off, AND 1153 goes off as does OR 1157. On
the next clock pulse received at terminal C of
flip-flop 1132, terminal Q goes off to remove the
reset signal from flip-flop 1125, and to remove
30 the input on signal to OR 1128 via line 1131.
However, as soon as flip-flop 1125 was reset,
terminal \bar{Q} of flip-flop 1125 went on via line 1126
which causes the output of OR 1128 to stay on and
hold a reset signal on counters 1133 and 1134.
35 Thus, at the end of the 7.5 second delivery time

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1 on counters 1133 and 1134, these counters are
reset and held in that condition by flip-flop
1125. This marks the end of one deliver and seek
cycle.

5 When flip-flop 1125 was reset by
flip-flop 1132, terminal Q of flip-flop 1125 went
off which output was transmitted via line 1160 to
terminals 1161 and 1162 and flip-flop 1163. Flip-
flop 1163 is a conventional "D" type flip-flop
10 including input data terminal D, clock terminal C,
and output terminal Q (terminal \bar{Q} is not shown
because it is not used). Terminal C receives one
kilohertz up clock pulse from terminal C1 via line
1164.

15 When the input to terminal D of
flip-flop 1163 goes off via line 1160, upon the
very next clock pulse received at terminal C,
terminal Q goes off via line 1165 to OR 1106,
which removes the reset signal from counters 1101
20 and 1102 allows them to begin counting pulses an
"seek" a valid inhalation for 7.5 seconds.

When flip-flop 1125 was reset,
terminal \bar{Q} went on to terminal 1127 which enabled
Solenoid Control and Monitor 400 to again energize
25 solenoid valves 20 and 22.

If during the time that counters
1101 and 1102 are counting pulses, a valid inhala-
tion occurs, then terminal 840 goes on which
resets counters 1101 and 1102. Thus, as long as
30 counters 1101 and 1102 get reset before 7.5 sec-
onds, AND 1116 never goes on and the Seek/Deliver
cycling is not actuated. The Seek/Deliver cycle
described was initiated by a low breath rate which
allowed timers 1101 and 1102 to turn on AND 1115

35

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1 which initiated delivery of oxygen for 7.5 seconds
as determined by delivery counters 1133 and 1134.

5 Oxygen flow for 7.5 seconds is also
initiated by a breath rate greater than 53 breaths
per minute as determined by count comparators 1166
and 1167. These counter comparators are identical
to comparators 669 and 676 of Flow Pulse Circuit
600. Terminal A < B IN of comparator 1166 is
10 clamped to ground 6 via line 1168. Terminals A >
B IN and A = B IN are both clamped high via line
1169 to voltage source V_{DD} . Terminals B_0 , B_1 , B_2
and B_3 of comparator 1166 are also clamped high by
1169 to voltage source V_{DD} . Terminal B = A OUT of
15 comparator 1166 is connected via line 1170 to
terminal B = A IN of comparator 1167. Terminal B
> A OUT of comparator 1166 is connected via line
1171 to terminal B > A IN of comparator 1167.
Terminal A > B IN of comparator 1167 is clamped
high via line 1169 to V_{DD} . Terminals B_0 , B_1 , B_2
20 and B_3 of comparator 1167 are clamped to ground 6
by line 1172.

Comparators 1166 receives input
data from terminals D_0 , D_1 , D_2 and D_3 of Three
Breath Timer 500 via lines 1173, 1174, 1175 and
25 1176 respectively to terminals A_0 , A_1 , A_2 and A_3
of comparator 1166 respectively (terminal A_0 being
the least significant bit). Terminals D_4 , D_5 , D_6
and D_7 of Three Breath Timer 500 are connected via
lines 1177, 1178, 1178, 1179 and 1180 respectively
30 to terminals A_0 , A_1 , A_2 and A_3 respectively of
comparator 1167 (terminal A_3 being the most signi-
ficant bit).

Because the terminals B_{0-3} of
35 comparator 1166 are clamped high and the terminals
 B_{0-3} of comparator 1167 are clamped low, a count

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1 of decimal 15 is represented in binary. Whenever
this count is greater than the input data count
received at the A_{0-3} terminals, then the output of
comparator 1167 at terminal B > A OUT goes on via
5 line 1181 to flip-flop 1182. A count of decimal
14 or less represented in binary terminals D_0-D_7
represents a short interval for Three Breath Timer
500 which corresponds to a frequent breath rate.
Thus, whenever Three Breath Timer 500 puts out a
10 three breath count of decimal 14 or less, then the
output of comparator 1167 goes on indicating a
breath rate higher than the value predetermined at
the B terminals of the comparators 1166 and 1167.

The output from comparator 1167 is
15 transmitted via line 1181 to flip-flop 1182 which
is a conventional "D" type flip-flop with reset
including data input terminal D which receives its
input on line 1181, input clock terminal C which
receives 10 kilohertz up clock pulses from termi-
20 nal C7 via line 1159, reset terminal R which is
connected via line 1130 to terminal 828, and
output terminal Q (terminal \bar{Q} is not shown because
it is not used).

If flip-flop 1182 receives an input
25 at terminal D, at the very next clock pulse re-
ceived at terminal C, Q goes on via line 1182 to
OR 1122. An on output from OR 1122 initiates the
deliver cycle as described in the paragraphs
above. Flip-flop 1182 can only be reset to stop
30 the Seek/Deliver cycle by a reset input at termi-
nal 828 (e.g. by setting BCD to zero flow rate or
turning the input of then on again).

The last function performed by
Seek/Deliver 100 is to delay energizing of sole-
35 noid valves 20 and 22 for 20 seconds when the unit

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1 is initially turned on to provide a warm-up time
to stabilize the electrical components described
herein. When the unit is initially turned on and
5 assuming a non-zero value is selected on the
oxygen flow dial, a reset signal exists at terminal
828 for approximately one second until capacitor
818 of Reset and Power Monitor 800 is charged.
During the time terminal 828 is on, the flip-flops
and counters of Seek/Deliver 1100 are either reset
10 or set with initial value. The on signal at
terminal 828 sets flip-flop 1125 on which sets
flip-flop 1163 output on, and via OR 1106, a reset
signal is held on seek counters 1101 and 1102 even
after terminal 828 goes off.

15 When the on signal at terminal 828
goes off, the output from OR 1128 goes off removing
the reset signal from counters 1133, 1134 and
1136, and counter 1133 begins counting input clock
pulses received at its terminal C. When terminals
20 Q_0 and Q_3 of counter 1134 go on after nine seconds,
this output is transmitted via lines 1147
and 1183 respectively to NAND 1135, which output
goes off via line 1184 to terminal C of warm-up
counter 1136 (counter 1136 identical to counters
25 1133 and 1134). At ten seconds, bits Q_{0-3} are
reset to zero and NAND 1135 goes back on.

Terminal EN of counter 1136 is
enabled continuously via line 1137 from V_{DD} .
Counter 1136 receives reset signal at terminal R
30 via line 132 and transmits output from terminals
 Q_0 , Q_1 , Q_2 and Q_3 via lines 1185, 1186, 1187 and
1188 respectively to NOR 1151. Counter 1136
receives the overflow from counter 1134 and each
input pulse to terminal C when NAND 1135 goes on
35 corresponds to a time duration of 10 seconds.

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1 When NAND 1135 again goes off and then back on at
20 seconds, terminal Q_1 of counter 1136 goes on.
When this occurs, the output from terminal Q_1 is
5 transmitted via line 1186 to terminal R of flip-
flop 1155 and OR 1157. When flip-flop 1155 is
reset, terminal \bar{Q} goes on to enable AND 1153 to
transmit signals from AND 1140. When OR 1157
10 receives the input from terminal Q_1 of counter
1136, the output of OR 1157 goes on which causes
the output of flip-flop 1132 at terminal Q to go
on after 1 clock pulse received at terminal C.
When flip-flop 1132 goes on, it resets counters
1133, 1134, 1136 and also flip-flop 1125 which
15 turns on terminal \bar{Q} of flip-flop 1125 and enables
Solenoid Control and Monitor 400 to energize
solenoid valves 20 and 22.

Once counter 1136 gets reset,
normally it never again receives an input from
NAND 1135 while power remains on because the
20 nature of the Seek/Deliver cycle never allows
counters 1133 and 1134 to achieve a count greater
than that corresponding to 7.5 seconds. Flip-flop
1155, after once receiving an input at terminal R
from terminal Q_1 of counter 1136, keeps terminal \bar{Q}
25 continuously energized unless a reset signal is
received from terminal 828. Additionally, once
counter 1136 is reset, its Q_1 output to OR 1157
remains off also so that only an output from AND
1140 can cause flip-flop 1132 output to go on.

30 The output of NOR 1151 goes on and
stays on when counter 1136 is reset after the
warm-up time because the inputs to NOR 1151 via
lines 1185, 1186, 1187, and 1188 go off. In the
event of some malfunction which allows counter
35 1134 to count to ten seconds without being reset,

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1 then Q₀ of counter 1130 goes on, NOR 1151 goes off, and AND 1140 goes off.

5 III. Summary of Advantages

As those skilled in the art will appreciate in light of the foregoing detailed description, the apparatus of the present invention provides a number of unique advantages which are not achieved or suggested by the prior art. Chief among these advantages is the fact that the apparatus provides short duration "custom tailored", relatively high flow rate pulses of medicinal gas which vary to meet and accommodate the patient's breathing efforts. By the same token, these "custom tailored" pulses of gas are carefully designed to achieve the physiological equivalent of the usual relatively low flow rate continuous administration of gas. In practice, it has been found that a system in accordance with the invention will save over 50% of the oxygen normally used in conventional continuous flow devices.

By virtue of the fact that the system of the invention tracks and calculates breathing rate and continuously calculates and delivers the medically desired pulse volume during each breath, the invention delivers a preprogrammed volume of gas per unit of time which meets both the physician's prescription and patient's needs. By preprogramming a patient breathing on a continuous cannula this device compensates for the variability of continuous cannula breathing and delivers a known volume over each minute of time.

Another consequence of the structure of the invention resides in the fact that the need

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1 for system humidification is largely if not en-
tirely eliminated. This results in a cost saving
inasmuch as no humidifier is required, and more-
over a propensity of such humidifiers to be a
5 significant vector for transmission of disease to
the patient is avoided.

Apart from the normal pulse mode opera-
tion of the apparatus, the system of the invention
is designed to automatically convert to continuous
10 flow operation in the event of power failure or
circuit malfunctions. Hence, in the event of such
abnormalities the patient is not deprived of
medicinal gas. As an adjunct to this safety
feature, appropriate alarms and signal lights are
15 also activated to warn attendants of the malfunc-
tion.

Another very significant feature of the
invention involves the so-called seek/deliver
function. That is to say, if the patient breath
20 rate is abnormally low (e.g., an apneic event) or
high, the seek/deliver circuitry forming a part of
the invention will deliver the relatively long
oxygen pulses on an intermittent basis while in
the interim monitoring the patient to ascertain if
25 normal breathing rates have resumed. In the
latter instance, the system again automatically
reverts to the normal pulse flow operation.

The overall reliability of the apparatus
hereof is further enhanced by virtue of the re-
zeroing function built into the control circuitry.
30 As noted above, in order to achieve the lowest
desirable pulse flow operation, it is necessary to
use very sensitive pressure or flow sensing equip-
ment. However, with such equipment there is a
35 possibility of ambient-induced signal drift which

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1 can lead to improper timing of delivered doses or
even possibly skipping of pulses. This potential
problem is overcome, however, by virtue of the de-
scribed rezeroing apparatus.

5 Finally, the invention has wide applica-
bility in diverse situations where supplemental
gas is necessary or desirable. Thus, the specifi-
cally disclosed "hospital" and "home" units are
but two examples of the scope of the invention.
10 If desired, portable units can be produced in
accordance with the invention to be carried by
patients or for use with oxygen concentrators;
such devices would be within the skill of the art
upon appreciation of the concepts of the present
15 invention.

While the specific circuitry herein
disclosed or described is designed to be incor-
porated on one or more semiconductor chips for
ease of manufacture, reliability and cost reduc-
20 tion, one skilled in the art will appreciate that
the present invention can be embodied using a
microprocessor with a program, for example, or
alternately with totally pneumatic instrumenta-
tion.

25 In addition, the breathing cycle sensing
means and correspondingly coupled measuring means
of the invention can at the discretion of the
designer be used to measure virtually any para-
meter or time interval which will characterize a
30 patient's breathing cycle or part thereof. While
in one disclosed embodiment herein the patient's
breath rate is effectively measured, in other
instances the duration of inhalation for example
could be measured and used in providing a value.
35 Accordingly, the terminology "breathing cycle

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1 sensing means" and "measuring means" as used
 herein should be taken in a broad sense to encom-
5 pass all such devices and embodiments which may be
 employed to derive characterizing information.

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1 Claims:

5 1. Apparatus adapted for connection between a source of medicinal gas and a patient-coupled gas delivery device for supplying pulse volumes of medicinal gas to the patient from time to time during the patient's breathing cycle, said apparatus comprising:

10 selectively actuatable valve means adapted for operable coupling between said gas source and device for selectively establishing and interrupting gas flow communication therebetween; and

15 means operably coupled with said valve means for selectively actuating the same, including--

 breathing cycle sensing means;

20 measuring means operably coupled with said sensing means for measuring a time interval characterizing at least a portion of at least one of said patient's breathing cycles, and for providing a value correlated with said measured time interval; and

25 means operably connecting said measuring means and said valve means for actuating the valve means in order to open the valve means and thereby establish said gas flow communication for a period of time which varies in response to said value provided by said measuring means.

30 3. The apparatus of Claim 1, said sensing means and measuring means being cooperatively designed for measuring said patient's breath rate.

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1 3. The apparatus of Claim 1, said
valve means being a three-way solenoid valve
having an output and a pair of inputs, said device
being coupled to the output of the valve, said
5 source being coupled with one of the inputs of
said valve, said sensing means being operably
coupled with the other of the input ports of said
valve means for establishing communication there-
through with said device when the valve means is
10 closed and gas flow communication between said
source and device is interrupted.

 4. The apparatus of Claim 1, said
sensing means comprising means operably coupled
15 with said patient's breathing passages for measur-
ing the pressure conditions in said breathing
passages.

 5. The apparatus of Claim 4, said
20 sensing means including:

 a diaphragm including a pair of opposed
faces, one of said faces being exposed
to the atmosphere; and
 conduit means operably communicating said
25 breathing passages and the other of said
diaphragm faces.

 6. The apparatus of Claim 5, there
being circuit means operably coupled with said
30 diaphragm, said circuit means including means for
compensating for changing ambient conditions and
corresponding ambient-induced signal drift in said
circuit means.

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1 7. The apparatus of Claim 5, said
sensing means further including airflow restrictor
means having two sides and being in parallel with
said diaphragm, one side of said restrictor means
5 being in communication with said other diaphragm
face, the other side of said restrictor means
being in communication with both said one dia-
phragm face and the atmosphere.

10 8. The apparatus of Claim 5, including
means operably coupled with said diaphragm for
developing a signal in response to a pressure
differential across said diaphragm.

15 9. The apparatus of Claim 1, including
a dual flow rate control apparatus in series with
said valve means and comprising:

20 a body presenting a first, high flow rate
path therethrough, and a separate,
second differently configured low flow
rate path therethrough, said actuating
means further having means coupled with
said dual flow rate control apparatus
25 for selectively and alternatively commu-
nicating said first and second paths
with said source and device.

30 10. The apparatus of Claim 1, said
measuring means including structure for measuring
and providing a value correlated with a time
interval characterizing a predetermined plurality
of said breathing cycles.

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1 11. The apparatus of Claim 10, said
predetermined plurality being three breathing
cycles.

5 12. The apparatus of Claim 1, said
connecting means including means for actuating
said valve means during a breathing cycle sub-
sequent to said at least one measured breathing
cycle.

10 13. The apparatus of Claim 10, said
measuring structure comprising a plurality of
timers, each timer including means for measuring
a time interval characterizing said predetermined
15 plurality of breathing cycles and means for pro-
viding a value correlated with said interval, the
number of said timers being equal to the prede-
termined plurality plus one.

20 14. The apparatus of Claim 1, said
apparatus being adapted for supplying said pulse
volumes in a manner to be substantially physiolo-
gically equivalent to a continuous supply of the
gas to said patient at a prescribed flow rate,
25 said apparatus including selectable means operably
coupled with said measuring means for giving a
respective prescribed flow rate value to a pre-
scribed flow rate, said connecting means having
means for receiving said time interval value, and
30 for generating an output signal in response there-
to, which output signal determines said period of
time said valve means is actuated to establish
said gas flow communication.

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1. 15. The apparatus of Claim 14, said
time interval being for at least one complete
breathing cycle of the patient including both
inhalation and exhalation.

5 16. The apparatus of Claim 14, said
time interval being for three complete breathing
cycles of the patient.

10 17. The apparatus of Claim 1, said
connecting means including means for actuating
said valve means only once during each of the
patient's breathing cycles.

15 18. The apparatus of Claim 1, said
connecting means including means for actuating
said valve means to establish said gas flow com-
munication, and to maintain the valve means in an
actuated condition for a predetermined period of
20 time, in response to a measured time interval
value either above or below predetermined limits.

25 19. The apparatus of Claim 1, said
valve means comprising a solenoid valve, said
valve being spring biased to the open position
thereof, and closed to interrupt said gas flow
communication upon energization of the valve,
whereby upon power failure said valve moves to the
open position thereof to establish said gas flow
30 communication.

35 20. The apparatus of Claim 19, said
connecting means having means for de-energization
of said valve means in response to one or more
preselected failures of the components of said
actuating means.

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1 21. The apparatus of Claim 1, said
connecting means including means for actuating
said valve means to open the same within about 5
5 to 50 milliseconds after the beginning of inhala-
tion during a breathing cycle subsequent to said
at least one measured cycle.

10 22. Apparatus adapted for connection
between a source of medicinal gas and a patient-
coupled gas delivery device for supplying pulse
volumes of medicinal gas to the patient during the
patient's breathing cycle, said apparatus compris-
ing:

15 selectively actuatable valve means adapted
for operable coupling between said gas
source and device for selectively estab-
lishing and interrupting gas flow com-
munication therebetween; and

20 means operably coupled with said valve means
for selectively actuating the same,
including--

breathing cycle sensing means;
measuring means operably coupled with
25 said sensing means for measuring a
parameter characteristic of at
least a portion of at least one of
the patient's breathing cycles, and
for providing a value correlated
with said measured parameter;

30 means operably connecting said measuring
means and said valve means for
actuating the valve means in order
to establish said gas flow communi-
cation for a period of time which
35 varies in response to said para-
meter value.

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1 23. In a method of supplying medicinal
gas to a patient during the patient's breathing
cycle, wherein medicinal gas is available from a
valve-controlled source thereof and the valve is
5 selectively actuated to deliver the gas to the
patient at selected times, the improved method
which comprises the steps of:

 measuring a parameter characterizing at least
 a portion of at least one of the pa-
10 tient's breathing cycles;
 providing a value correlated with said mea-
 sured parameter; and
 actuating said valve to open the same and
 supply a pulse volume of gas to the
15 patient for a period of time which
 varies in response to said value.

 24. The method of Claim 23, said value
being a time interval correlated value charac-
20 terizing said at least a portion of at least one
breathing cycle.

 25. The method of Claim 24, including
the step of measuring a characteristic time inter-
25 val relating to a plurality of said breathing
cycles.

 26. The method of Claim 25, said plu-
rality being three cycles.

 27. The method of Claim 24, said time
interval being at least one complete breathing
cycle including inhalation and exhalation.

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1 28. The method of Claim 23, including
the step of actuating said valve within about 5 to
50 milliseconds after the beginning of inhalation
by the patient during each breathing cycle.

5 29. The method of Claim 23, including
the step of actuating said valve means during a
subsequent breathing cycle occurring after said at
least one measured cycle.

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1 30. A fluid flow restricting device,
comprising:

5 a flow selector element presenting a pair of
opposed faces and two sets of spaced
apart orifices therethrough, the orifi-
ces of each set being of different
effective dimensions respectively; and

10 a body disposed about said element and having
a wall surface adjacent each of said
element faces, said body having first
and second separate fluid inlet passage-
ways therethrough and passing through
one of said body wall surfaces, said
body also having corresponding first and
15 second, separate, fluid outlet passage-
ways therethrough and passing through
the other of said body wall surfaces,

20 said first inlet passageway and said corres-
ponding first outlet passageways, and
said second inlet passageway and said
corresponding second outlet passageway,
being arranged for fluid flow communi-
cation therebetween,

25 the individual orifices of each set thereof
being oriented in mated pairs for pre-
senting a plurality of orifice pairs
each including one orifice from each set
thereof,

30 each of said orifice pairs being located for
alternately and simultaneously estab-
lishing fluid flow communication between
said corresponding inlet and outlet
passageways,

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1 said element and body being mounted for rela-
 tive shifting movement therebetween for
 selective, alternative establishment of
5 communication between said corresponding
 inlet and outlet passageways through
 separate orifice pairs.

10 31. The device of Claim 30, said selec-
 tor element being rotatable relative to said body.

15 32. The device of Claim 31, said ele-
 ment being circular, said orifices being oriented
 in two circularly arranged sets thereof, said sets
 being located along different radii of said ele-
 ment.

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1 33. In apparatus adapted for connection
between a source of medicinal gas and a patient-
coupled gas delivery device for supplying rela-
tively short duration gas pulse volumes to the
5 patient from time to time, said apparatus includ-
ing valve means operably coupled between said
source and device, and means for actuating the
valve means from time to time to open the valve
means and establish gas flow communication between
10 the source and device, the improvement which com-
prises:

means for measuring the breath rate of said
patient, and for determining an abnormal
breath rate condition where the pa-
15 tient's breath rate is above or below
predetermined breath rate limits; and
means coupled with said breath rate measuring
and determining means and said valve and
device for opening said valve means and
20 continuously supplying said gas to said
patient for a period of time greatly in
excess of one of said short duration gas
doses, followed by closing of said valve
means after said period of time, in
25 response to the determination of an
abnormal breath rate condition.

34. The apparatus of Claim 33, said
period of time being about 7.5 seconds.
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35. The apparatus of Claim 33, includ-
ing means for again measuring said patient's
breath rate at the end of said period of time
after said valve means is closed.
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1 36. In pulse translation apparatus for
translating a series of input pulses occurring at
variable intervals into a series of corresponding
5 output pulses each commencing in predetermined
time relationship to the occurrence of a corres-
ponding input pulse and of a duration correlated
in predetermined manner with the intervals of
occurrence of a predetermined plurality of preced-
ing input pulses;

10 input means for receiving said input pulses;
output means for delivering said output
pulses;

15 a plurality of timer means greater in number
than said plurality of preceding input
pulses and each operable for measuring
the time interval between events charac-
terizing the occurrence of the first and
the last of a particular instance of
20 said plurality of preceding input pulses
and for generating an output pulse of
duration different from but correlated
in predetermined manner with said inter-
val;

25 means for sequentially coupling each of said
timer means with said input means in
response to a successive one of said
input pulses; and

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1 means for sequentially decoupling each of
said timer means from said input means
and for operably coupling said generat-
5 ing means with said output means for a
period correlated with said time inter-
val of a corresponding instance of said
plurality of input pulses measured by
said measuring means, in response to the
10 last of said instance of said plurality
of input pulses.

37. The apparatus of Claim 1, including
means operably coupled with said measuring means
for generating a prescribed gas flow rate signal
15 correlated with a physician-prescribed continuous
gas flow rate, said measuring means including
means for generating a signal corresponding to
said measured time interval, memory means having
data storage cells individually accessible in
20 response to a pair of input signals, each of said
cells containing a time interval value correlated
with both of said signals, and means operably
coupling said flow rate signal generating means
and said time interval signal generating means
25 with said memory means to provide said cell-
accessing input signals to said memory means.

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1 38. The apparatus of Claim 37, said
connecting means including electronic circuit
calculating means for receiving respective time
interval values, and for generating a calculated
5 output signal, said calculated output signals
serving to open said valve means for periods of
time such that the pulse volumes of said gas
delivered to said patient are substantially phy-
siologically equivalent with said physician-
10 prescribed continuous gas flow rate.

 39. The apparatus of Claim 38, said
circuit calculating means including first circuit
means operably coupled with said memory means for
15 receiving said respective time interval values,
and for generating corresponding scaled output
signals correlated with said time interval values,
and second circuit means operably coupled with
said first circuit means for receiving said scaled
20 output signals, said second circuit means also
being coupled with said means for generating a
signal corresponding to said measured time inter-
val for receiving said corresponding signals, and
second circuit means including apparatus for
25 generating said calculated output signals in
response to and correlated with said scaled output
signals and said corresponding signals.

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1 40. The apparatus of Claim 37, said
memory means having a plurality of discrete data
retention zones each including a plurality of said
5 cells, the cells of each data retention zone
containing time interval values corresponding to
different intended environments of use of said
apparatus, there being means operably coupled with
said memory means for selecting a respective one
10 of said data retention zones.

15 41. The apparatus of Claim 1, including
structure for sensing the flow rate of gas within
said delivery device during at least a portion of
the patient's breathing cycle.

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[received by the International Bureau on 11 August 1987 (11.08.87);
original claims 1-29 cancelled; claims 30-41 replaced by new claims 30-57 (12 pages)]

1 30. A fluid flow restricting device,
 comprising:

 a flow selector element presenting a pair of
 opposed faces and two sets of spaced
5 apart orifices therethrough, the ori-
 fices of each set being of different
 effective dimensions respectively; and

 a body disposed about said element and having
 a wall surface adjacent each of said
10 element faces, said body having first
 and second separate fluid inlet passage-
 ways therethrough and passing through
 one of said body wall surfaces, said
 body also having corresponding first and
15 second, separate, fluid outlet passage-
 ways therethrough and passing through
 the other of said body wall surfaces,

 said first inlet passageway and said corres-
 ponding first outlet passageways, and
20 said second inlet passageway and said
 corresponding second outlet passageway,
 being arranged for fluid flow communica-
 tion therebetween,

 the individual orifices of each set thereof
25 being oriented in mated pairs for pre-
 senting a plurality of orifice pairs
 each including one orifice from each set
 thereof,

 each of said orifice pairs being located for
30 alternately and simultaneously estab-
 lishing fluid flow communication between
 said corresponding inlet and outlet
 passageways,

1 said element and body being mounted for
relative shifting movement therebetween
for selective, alternative establishment
of communication between said corres-
5 ponding inlet and outlet passageways
through separate orifice pairs.

31. The device of Claim 30, said selec-
tor element being rotatable relative to said body.

10 32. The device of Claim 31, said ele-
ment being circular, said orifices being oriented
in two circularly arranged sets thereof, said sets
being located along different radii of said ele-
15 ment.

33. (Cancelled)

34. (Cancelled)

20 35. (Cancelled)

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1 36. In pulse translation apparatus for
translating a series of input pulses occurring at
variable intervals into a series of corresponding
output pulses each commencing in predetermined
5 time relationship to the occurrence of a corresponding input pulse and of a duration correlated in predetermined manner with the intervals of occurrence of a predetermined plurality of preceding input pulses;

10 input means for receiving said input pulses;
output means for delivering said output pulses;

15 a plurality of timer means greater in number than said plurality of preceding input pulses and each operable for measuring the time interval between events characterizing the occurrence of the first and the last of a particular instance of said plurality of preceding input pulses
20 and for generating an output pulse of duration different from but correlated in predetermined manner with said interval;

25 means for sequentially coupling each of said timer means with said input means in response to a successive one of said input pulses; and

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1 means for sequentially decoupling each of
said timer means from said input means
and for operably coupling said generat-
ing means with said output means for a
5 period correlated with said time inter-
val of a corresponding instance of said
plurality of input pulses measured by
said measuring means, in response to the
last of said instance of said plurality
10 of input pulses.

37. (Cancelled)

38. (Cancelled)

15 39. (Cancelled)

40. (Cancelled)

20 41. (Cancelled)

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1 42. Apparatus adapted for connection between
a source of medicinal gas and a patient-coupled
gas delivery device for supplying pulse volumes of
medicinal gas from time to time during the pa-
5 tient's breathing cycles, said apparatus compris-
ing:

selectively actuatable valve means adapted
for operable coupling between said gas
source and device for selectively estab-
10 lishing and interrupting gas flow commu-
nication therebetween; and

means operably coupled with said valve means
for selectively actuating the same
including --

15 breathing cycle sensing and measuring
means for tracking the patient's
breathing efforts over plural
breathing cycles, and for measuring
a variable magnitude parameter
20 incident to at least one reference
breathing cycle, said variable
magnitude parameter being at least
partially predictive of the volume
of said gas required by said pa-
25 tient during a medicinal gas-
supplemented breathing cycle;

means operably coupled with said sensing
and measuring means for determining
a variable magnitude value corre-
30 lated with said measured parameter
and representative of said required
volume of medicinal gas; and

1 means coupling said value-determining
means and said valve means for
opening said valve means during
said medicinal gas-supplemented
5 breathing cycle for delivering to
said patient said required volume
of medicinal gas, said volume being
variable in response to the magni-
tude of said determined value for
10 supplying to said patient variable
volumes of said gas during differ-
ent gas-supplemented breathing
cycles.

15 43. The apparatus as set forth in Claim
42, said breathing cycle sensing and measuring
means including time measuring means for measuring
elapsed time over a predetermined plurality of
breathing cycles, said measured parameter being
20 said elapsed time.

25 44. The apparatus as set forth in Claim
42, said value-determining means including read-
only memory means for storing a plurality of
predetermined values, there being means for sel-
ecting one of said values in at least partial
response to the measured magnitude of said vari-
able magnitude parameter.

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1 45. The apparatus as set forth in Claim
44, said value-selecting means including means for
addressing respective value-storing locations in
said read-only memory means, said addressing means
5 including means operably connecting said read-only
memory means with said breathing cycle sensing and
measuring means and with means for selecting any
one of a number of prescribable gas flow rates,
said breathing cycle sensing and measuring means
10 and said gas flow-selecting means each providing a
respective data input to said read-only memory
means, said data inputs defining a respective
value-storing location in said read-only memory
means whereby said value is selected depending
15 upon said data inputs.

 46. The apparatus as set forth in Claim
42, said value-determining means being operable
for providing a constant minute volume of medici-
20 nal gas to the patient.

 47. The apparatus as set forth in Claim
42, including structure operably coupled with said
valve means for preventing opening thereof and
25 hence delivery of said medicinal gas more than
once during each of the patient's breathing cy-
cles.

 48. The apparatus as set forth in Claim
30 42, said at least one reference breathing cycle
being different than said gas-supplemented breath-
ing cycle.

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1 49. The apparatus as set forth in Claim
48, said gas-supplemented breathing cycle occurring after said at least one reference breathing cycle.

5 50. The apparatus as set forth in Claim
42, said breathing cycle sensing and measuring means including --

means operably coupled with said patient's
10 breathing passages for measuring pressure conditions in said breathing passages, and for producing signals representative of said pressure conditions;
and

15 means coupled with said pressure condition measuring means for compensating for drift of said signals wherein said drift is nonrepresentative of said pressure conditions.

20 51. The apparatus as set forth in Claim
42, said apparatus presenting a gas flow path from said source to said valve means and thence to said device, said coupling means including pneumatic
25 means operably interposed in said gas flow path and cooperable with said valve means for delivery of said variable required volumes of medicinal gas.

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1 52. The apparatus as set forth in Claim
51, said pneumatic means comprising a pressure
regulator operably coupled between said source and
said valve means,

5 said regulator having an exit port,
said valve means having an inlet port,
said outlet and said inlet being intercoupled
by means of a delivery tube,

10 said valve means being shiftable between an
open position for allowing gas flow
communication between said source and
said device through said regulator, and
an alternate position for preventing
said communication,

15 said source supplying said gas at a source
pressure,

20 said regulator being operable to deliver said
gas through said outlet into said deli-
very tube at a delivery pressure and to
maintain said delivery pressure at a set
pressure less than said source pressure
when said valve means is in said open
position and said gas is flowing through
said regulator,

25 said regulator being operable to allow said
delivery pressure of said gas in said
tube to rise to a level above said set
pressure when said valve means is in
said alternate position and no gas is
30 flowing through said regulator thereby
storing a pulse volume of said gas in
said tube,

1 said means for opening said valve means being
operable to shift said valve means to
said open position thereby delivering
said pulse volume of said gas to said
5 device.

53. The apparatus as set forth in Claim
51, said pneumatic means including a selectively
actuatable, dual flow rate control apparatus
10 coupled in series with said valve means and com-
prising:

 a body presenting a first, high flow rate
 path therethrough, and a separate,
 second, low flow rate path therethrough,
15 said actuating means further including means
 for selectively shifting said body to a
 first position for allowing gas flow
 communication between said source and
 said valve means through said first
20 path, and alternately to a second posi-
 tion for allowing gas flow communication
 between said source and said valve means
 through said second path.

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1 54. The apparatus as set forth in Claim
53, said actuating means being operably coupled
with both said valve means and said dual flow rate
control apparatus for:

5 (1) maintaining said valve means in a con-
tinuously open position when said body
is in said second position whereby a
prescribed continuous medicinal gas flow
is delivered to the patient; and

10 (2) selectively opening said valve means
during each medicinal gas-supplemented
breathing cycle for a time period corre-
lated with said determined value when
said body is in said first position, in
15 order to deliver said required volumes
of medicinal gas to the patient.

 55. The apparatus as set forth in Claim
53, said actuating means including means for
20 automatically shifting said body to said second
position and said valve means to said open posi-
tion in response to the occurrence of one or more
preselected failures of said actuating means.

25 56. The apparatus as set forth in Claim
5, said actuating means including means for de-
tecting patient breath rate outside a predeter-
mined range, and for actuating said control appa-
ratus to shift said body to said second position
30 and said valve means to said open position thereof
for a predetermined amount of time in response to
detection of said breath rate outside said range.

1 57. The apparatus as set forth in Claim
42, said breathing cycle sensing and measuring
means including means for sensing a predetermined
5 pressure condition point in a gas supplemented
breathing cycle, and for subsequently verifying
the occurrence of said predetermined point before
said opening of said valve means.

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Independent Claim 42 defines apparatus for selective delivery of variable volume doses of medicinal gas to a patient.

Independent Claim 30 is directed to a valve device as described in the specification.

Independent Claim 36 defines electrical pulse translation apparatus.

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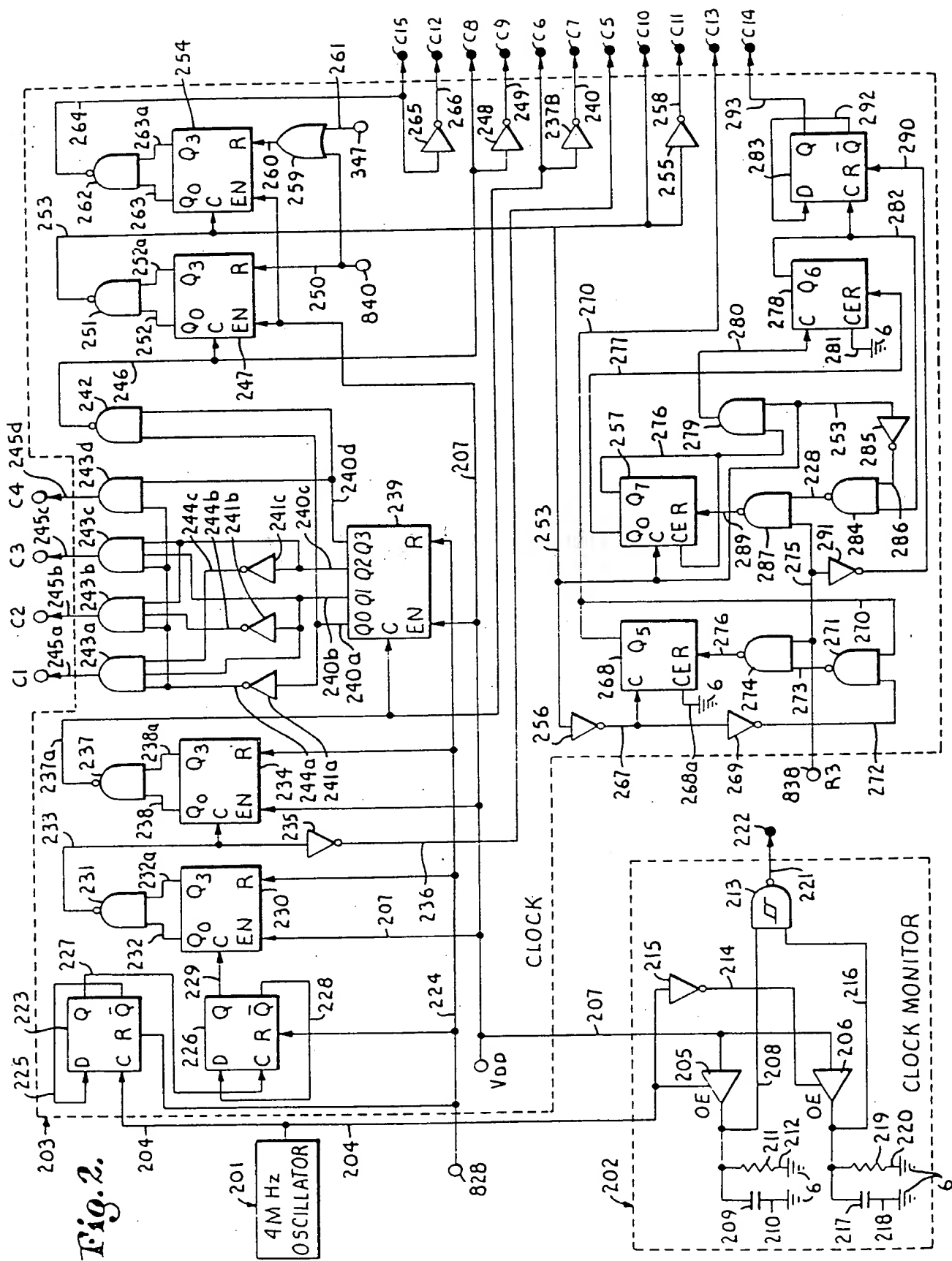
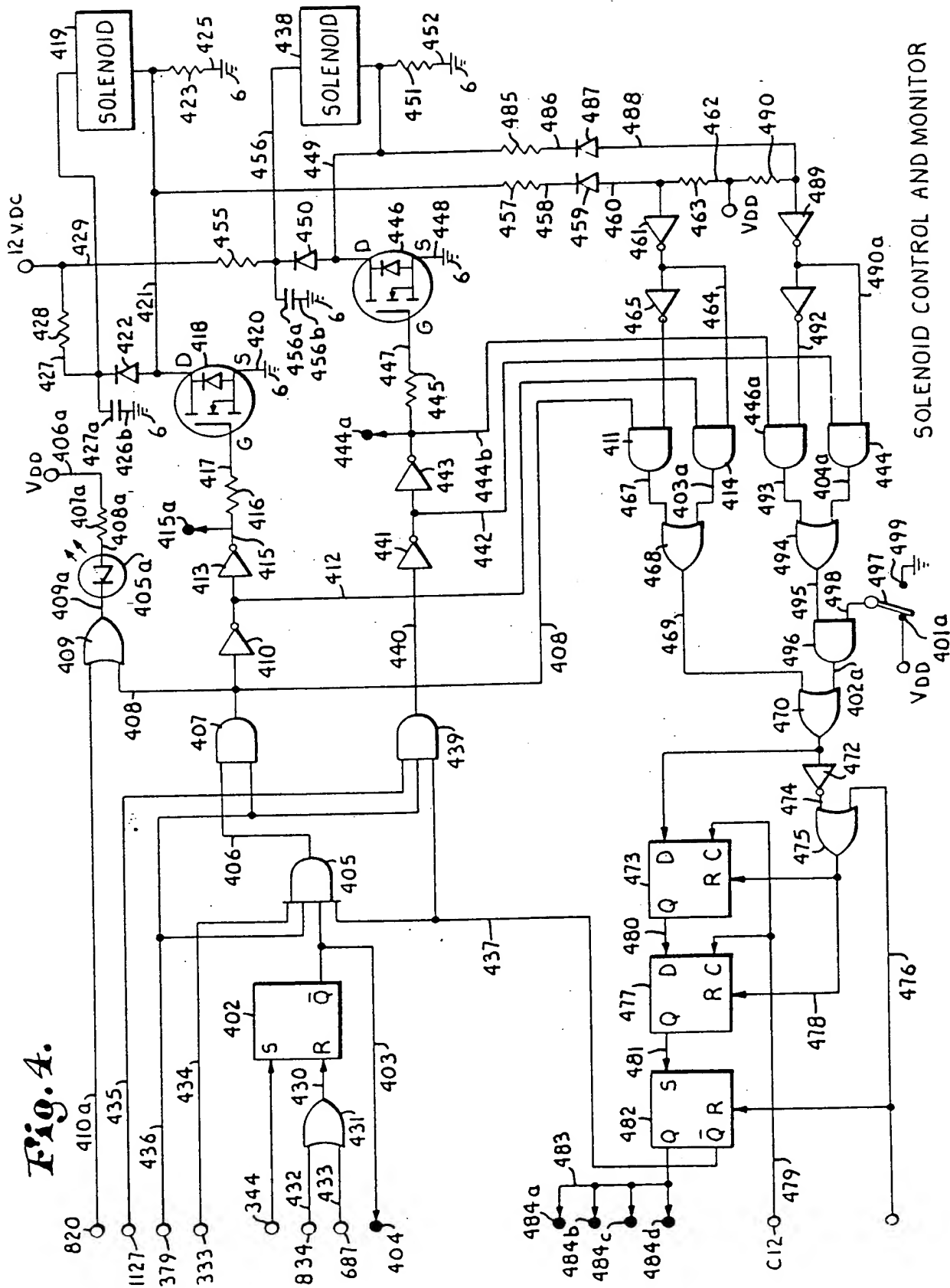


Fig. 2.

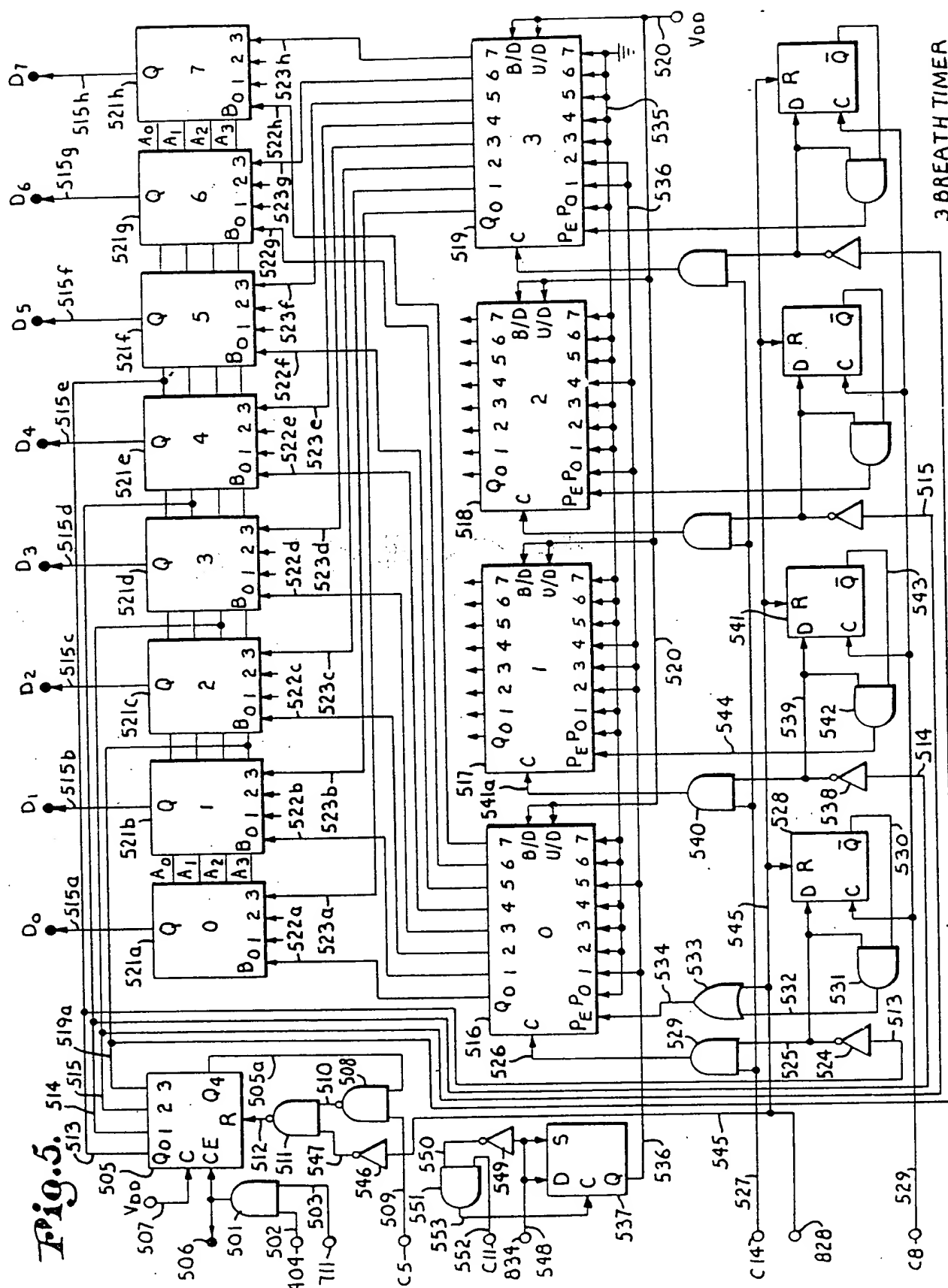
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Fig. 4.



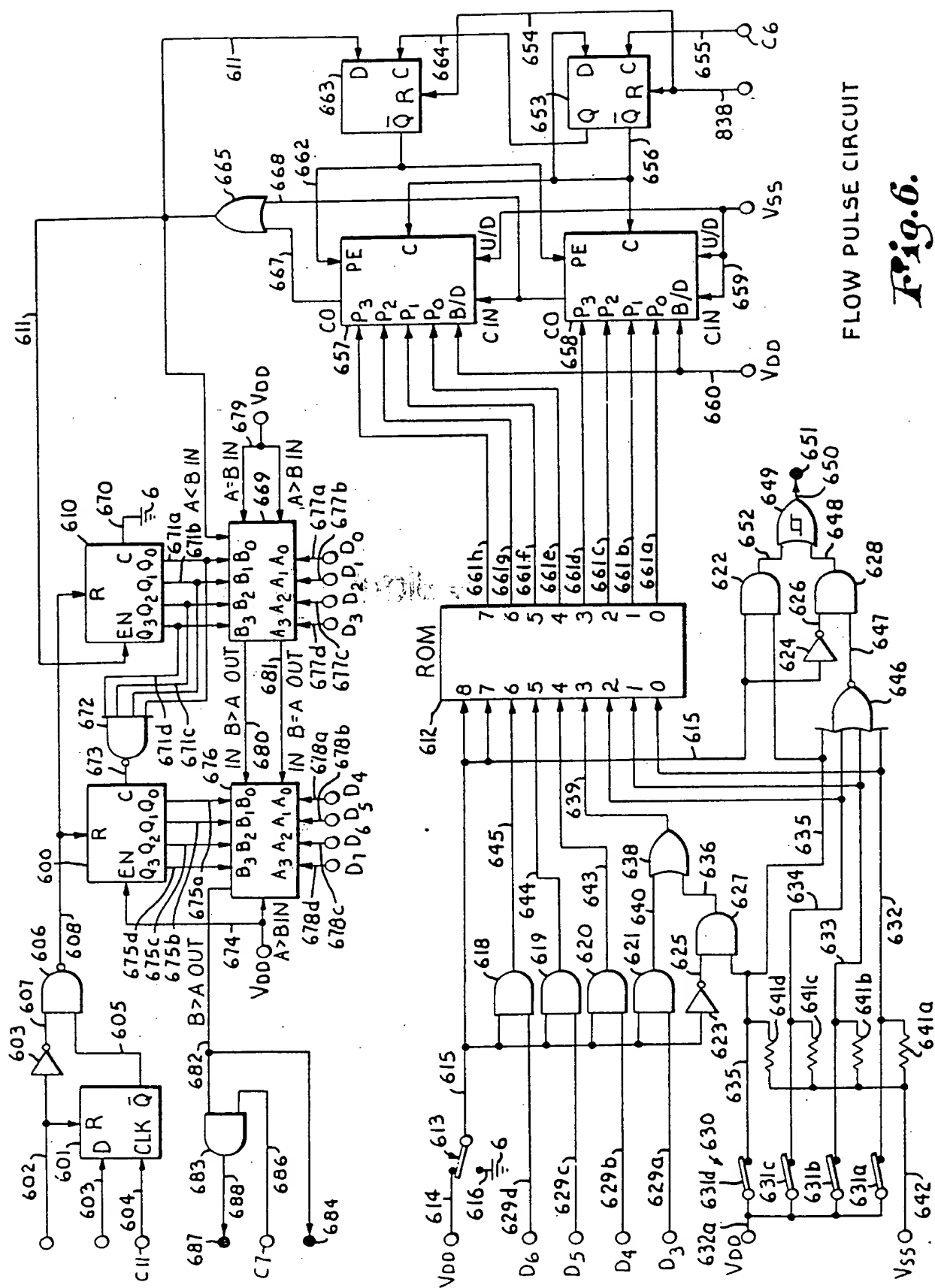
SOLENOID CONTROL AND MONITOR

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FLOW PULSE CIRCUIT

Fig. 6.

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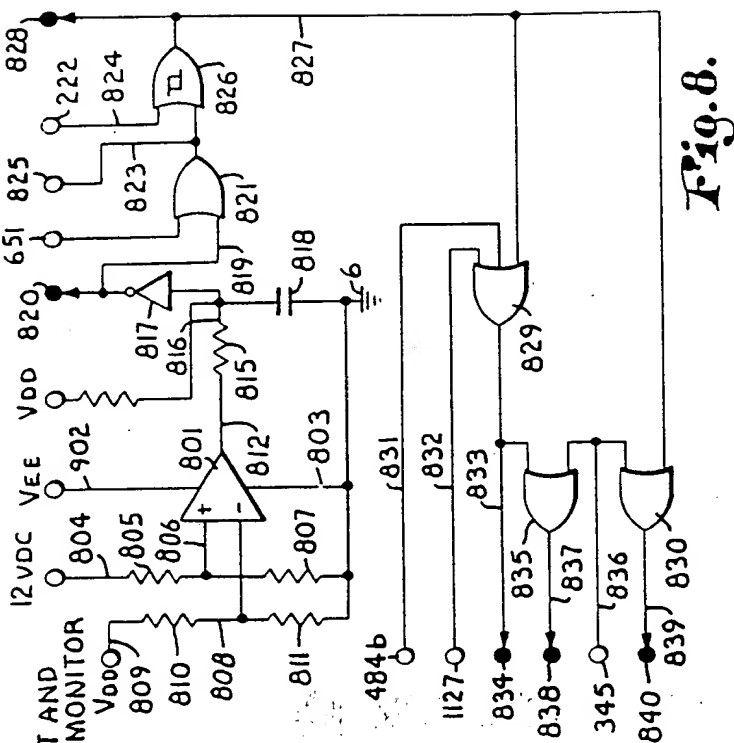


Fig. 8.

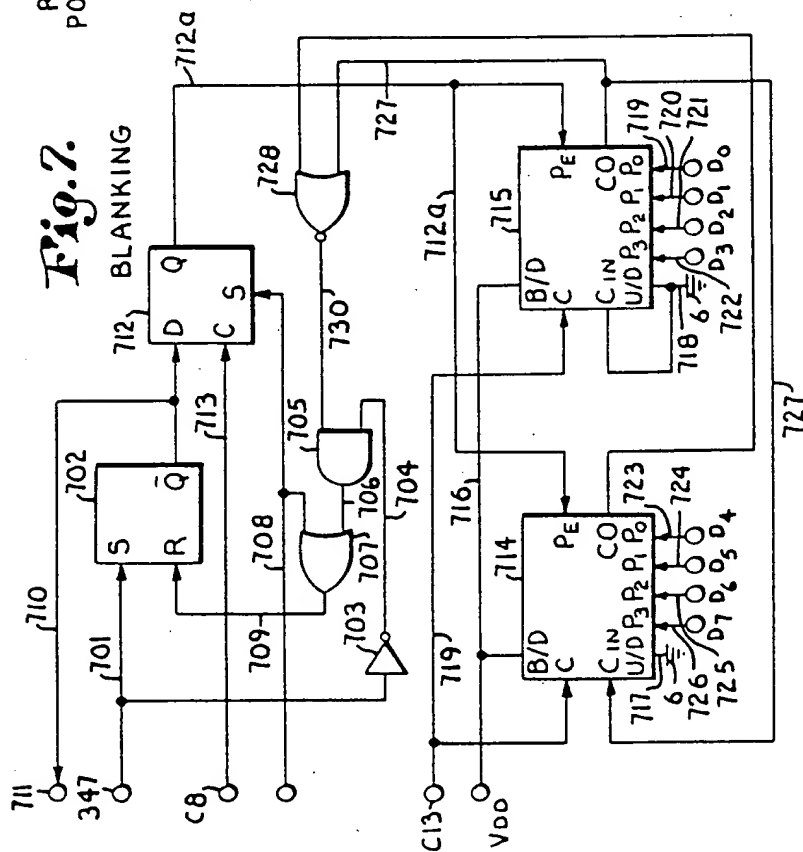


Fig. 9.

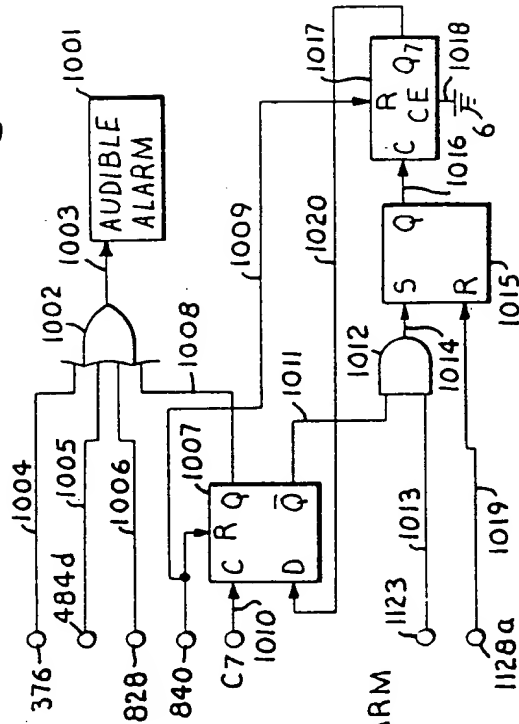
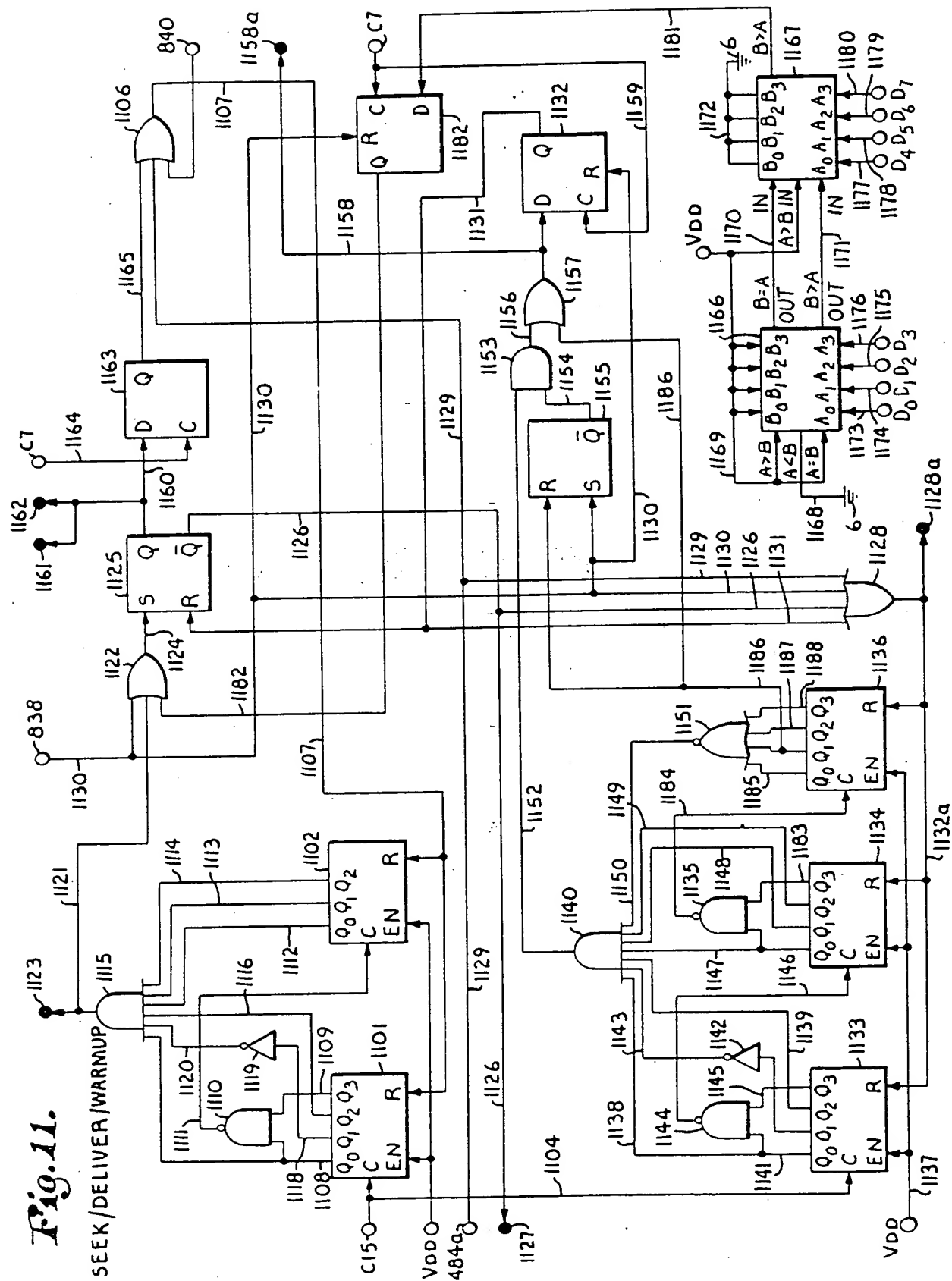


Fig. 10.

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Fig. 11.

SEEK/DELIVER/WARMUP



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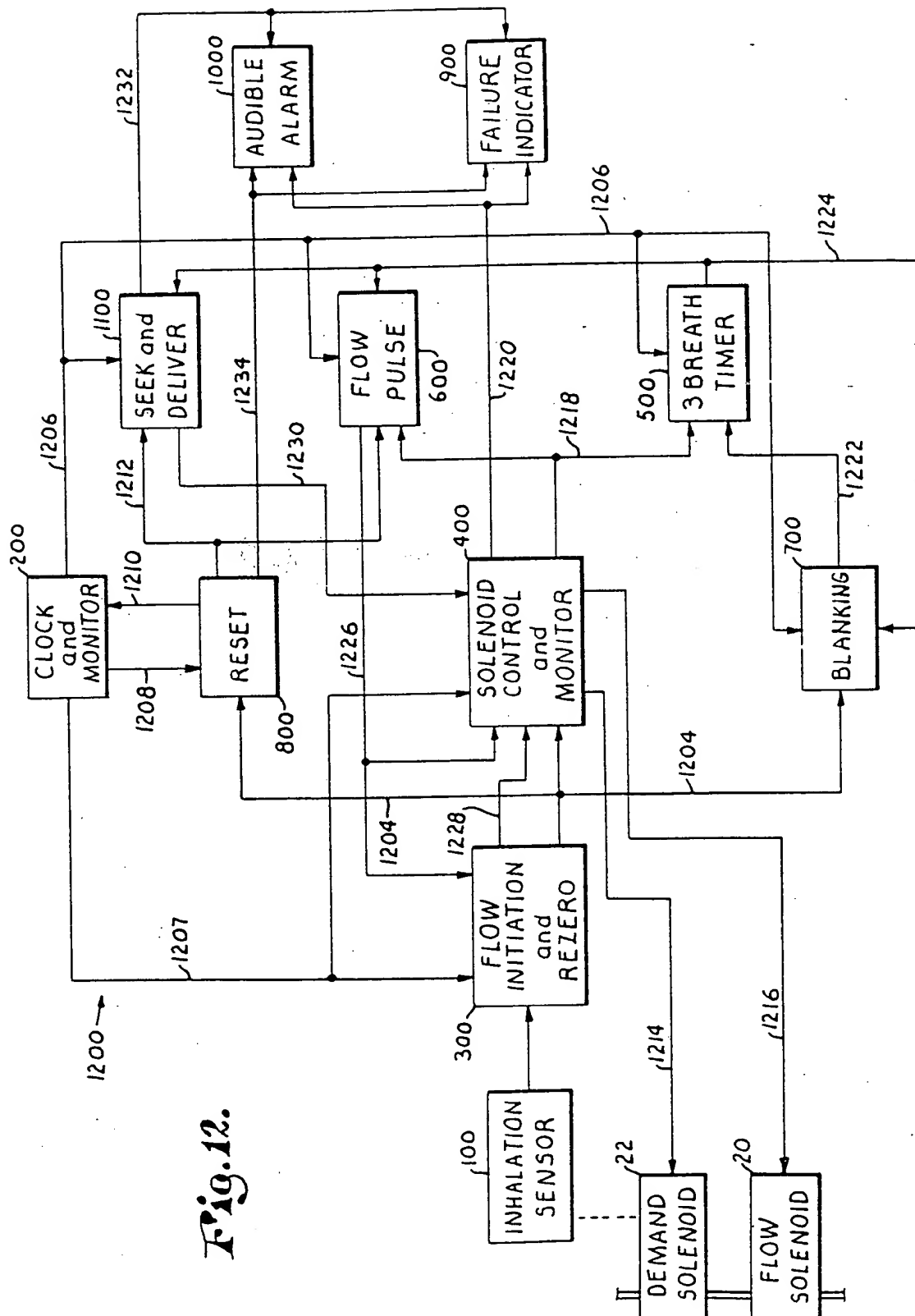


Fig. 12.

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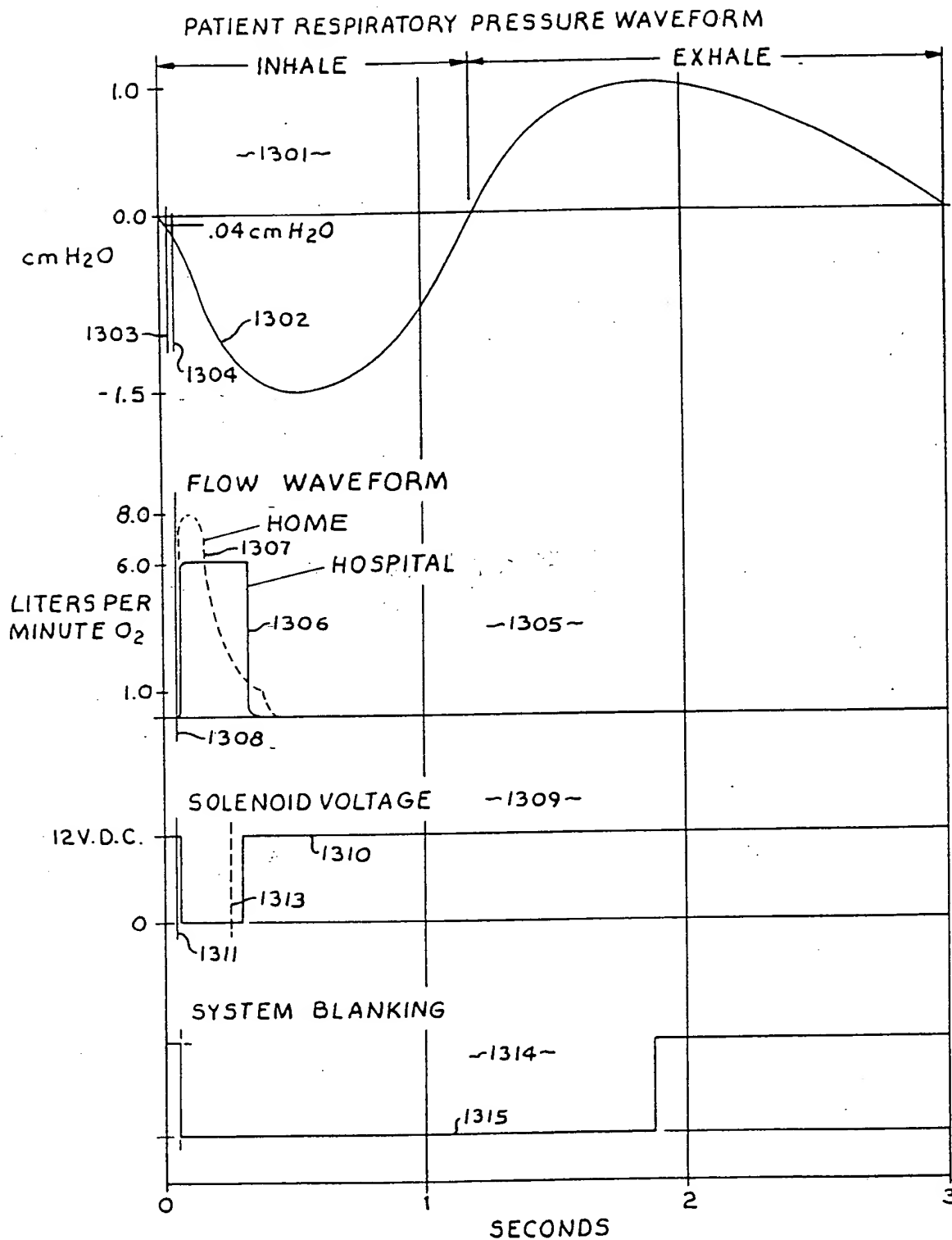


Fig. 13.

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Fig.15.

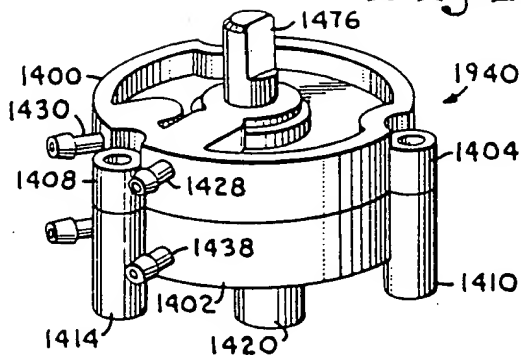


Fig.16.

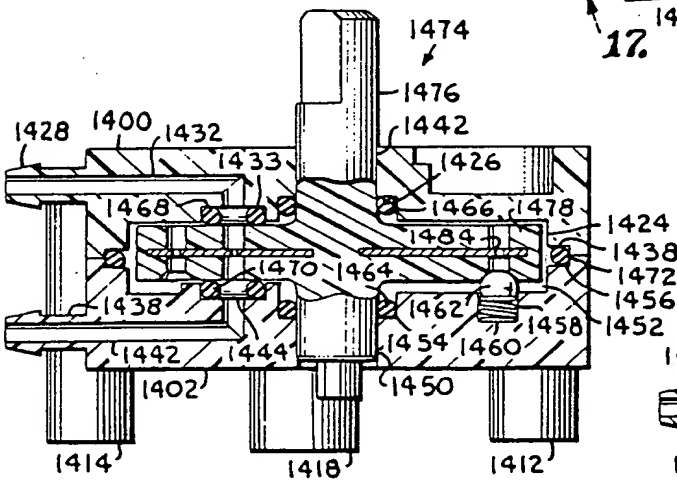
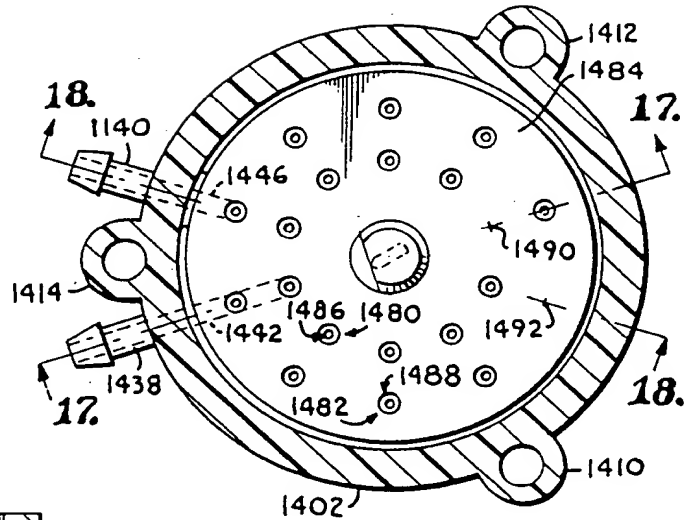


Fig.17.

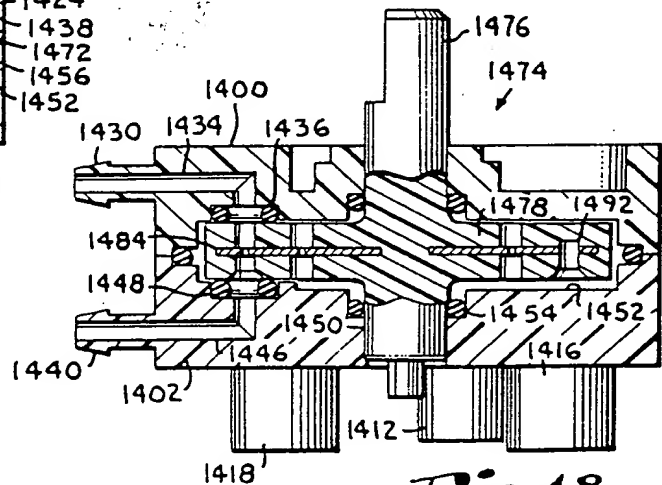
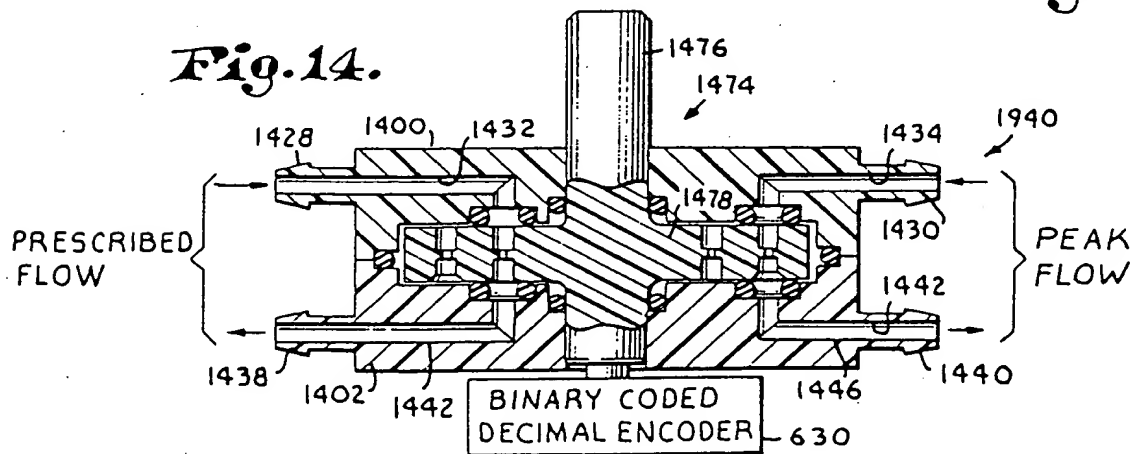


Fig.18.

Fig.14.



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Fig. 20.

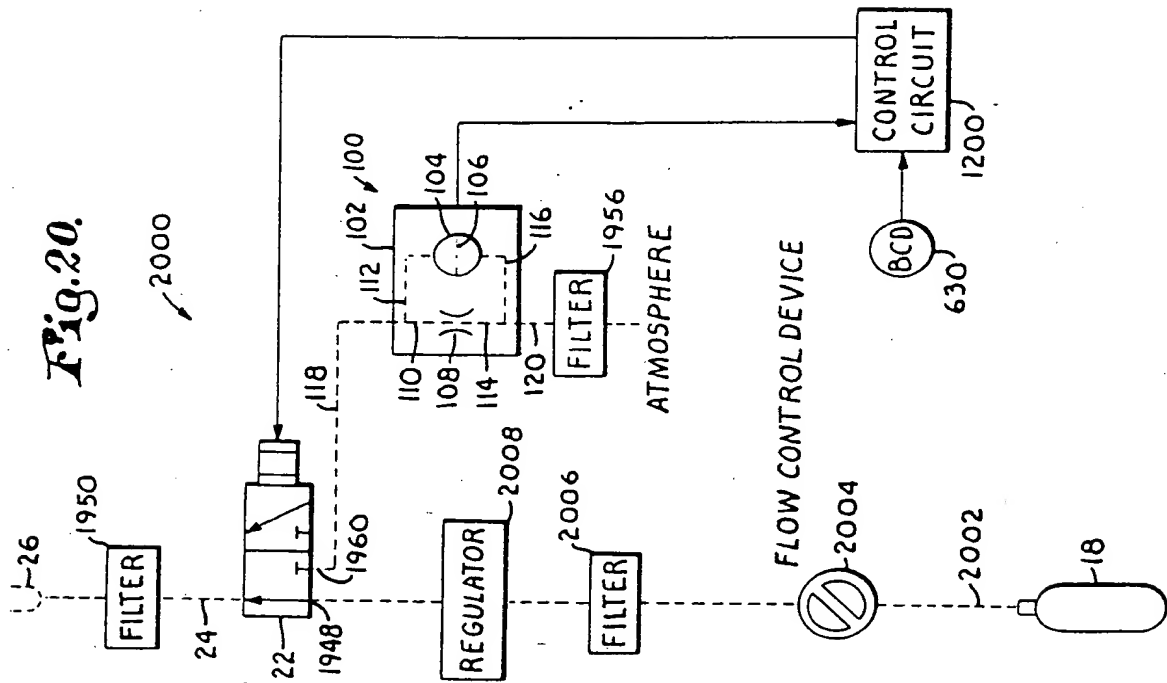
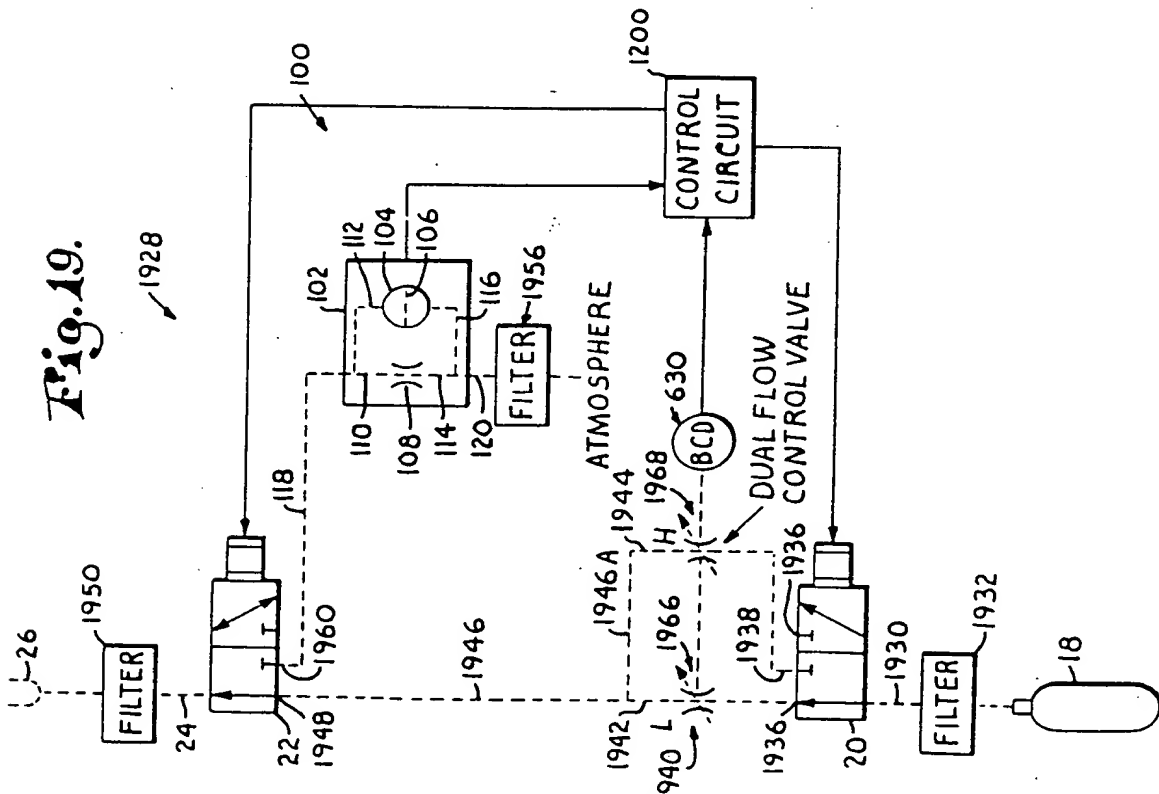


Fig. 19.



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INTERNATIONAL SEARCH REPORT

International Application No PCT/US87/00773

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 3

According to International Patent Classification (IPC) or to both National Classification and IPC
 IPC(4): A61M 16/00
 U.S. C1: 128/204.21

II. FIELDS SEARCHED

Minimum Documentation Searched 4	
Classification System	Classification Symbols
U.S.	128/204.21-204.26, 205.24 137/624.11, 625.21, 625.22, 625.65, 597

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 4

III. DOCUMENTS CONSIDERED TO BE RELEVANT 14

Category 5	Citation of Document, 16 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No. 18
$\frac{Y}{X}$	US,A, 3,831,596 (CAVALLO) 27 AUGUST 1974 See entire document	1-6, 8, 12, 17, 18, 21-24, 27-29 5, 6, 8
$\frac{X}{Y}$	IT,A, 716,593 (DRAGER) 10 OCTOBER 1966 See entire document	1-5, 7, 8, 12 17-24, 27-29, 41 5, 7, 8
$\frac{X}{Y}$	US,A, 4,457,303 (DURKAN) 03 JULY 1984 See entire document	1-4, 10-12, 14, 17-24, 27-29, 41 5-8
$\frac{X}{Y}$	US,A, 2,830,580 (SAKLAD ET AL) 15 APRIL 1958 See entire document	1, 2, 4-6, 8, 9 12, 17, 18, 21-24, 27-29, 33-35, 41 7
Y	US,A, 2,600,099 (DETREZ) 10 JUNE 1982 See entire document	30-32

* Special categories of cited documents: 15

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 1
 03 JUNE 1987

Date of Mailing of this International Search Report 1

24 JUN 1987

International Searching Authority 1

ISA/US

Signature of Authorized Officer 10

Karin Reichle

Karin Reichle

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